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(71) Applicant: THE DOW CHEMICAL COMPANY
2030 Dow Center Abbott Road
Midland, MI 48640(US)

(72) Inventor: Stevens, James C.
2704 Georgetown Drive
Midland, Michigan 48640(US)
Inventor: Timmers, Francis J.
4605 Lund Drive
Midland, Michigan 48640(US)
Inventor: Wilson, David R.
1220 West Stewart Road
Midland, Michigan 48640(US)
Inventor: Schmidt, Gregory F.
306 Helen Street
Midland, Michigan 48640(US)
Inventor: Nickias, Peter N.
4512 North Saginaw Road, Apartment 1120
Midland, Michigan 48640(US)
Inventor: Rosen, Robert K.
2612 Abbott Road No. 11
Midland, Michigan 48640(US)
Inventor: Knight, George W.
1618 North Road
Lake Jackson, Texas 77566(US)
Inventor: Lai, Shih-yaw
4523 Bermuda Drive
Sugar Land, Texas 77479(US)

(74) Representative: Burford, Anthony Frederick et al
W.H. Beck, Greener & Co. 7 Stone Buildings
Lincoln's Inn
London WC2A 3SZ(GB)

(54) **Constrained geometry addition polymerization catalysts, processes for their preparation, precursors therefor, methods of use, and novel polymers formed therewith.**

(57) Metal coordination complexes comprising a metal of Group 3 (except Sc), 4-10 or the lanthanide series and a delocalized Π-bonded moiety have said moiety substituted with a constrain-inducing moiety which reduces the angle at the metal between the centroid of said Π-bonded moiety and at least one remaining substituted. Preferably, the complexes comprise a cyclopentadienyl or substituted cyclopentadienyl group forming part of a ring structure in which the metal is both bonded to an adjacent convalent moiety and held in association with the (substituted) cyclopentadienyl moiety. Complexes of said preferred structure are not necessarily constrained sufficiently to reduce the said angle. Amidosilane and amidoalkanediyl compounds are particularly preferred.

The compl xes of the invention form addition polymerization catalysts with activing cocatalysts such as Lewis acids, ammonium salts, oxidizing agents and, especially, aluminum compounds, particularly aluminum trialkyls.

Novel polym rs, including EIPE resins and pseudo-random copolymers, can be obtained using the catalysts of the invention.

EP 0 416 815 A2

CONSTRAINED GEOMETRY ADDITION POLYMERIZATION CATALYSTS, PROCESSES FOR THEIR PREPARATION, PRECURSORS THEREFOR, METHODS OF USE, AND NOVEL POLYMERS FORMED THEREWITH

The present invention relates to metal coordination complexes having constrained geometry. The invention also relates to certain novel addition polymerization catalysts comprising such metal complexes having constrained geometry. Furthermore, the invention relates to methods for the polymerization of addition polymerizable monomers and to the resulting polymers.

Because of the unique exposure of the active metal site of the metal coordination complexes having constrained geometry, catalysts resulting therefrom have unique properties. Under certain conditions, the catalysts of the invention are capable of preparing novel olefin polymers having previously unknown properties due to their unique facile abilities to polymerize α-olefins, diolefins, hindered vinylidene aliphatic monomers, vinylidene aromatic monomers and mixtures thereof.

Numerous metal coördination complexes are known in the art including such complexes involving monocyclopentadienyl groups and substituted monocyclopentadienyl groups. The present metal coordination complexes differ from those previously known in the art due to the fact that the metal is bound to a delocalized substituted Π-bonded moiety in a manner so as to induce a constrained geometry about the metal. Preferably the metal is bound to a cyclopentadienyl, substituted cyclopentadienyl or similar group by both a η^5-bond and a bridging linkage including other ligands of the metal. The complexes also preferably include metals having useful catalytic properties.

Also previously known in the art are transition metal coordination complexes known as tucked complexes. Such complexes are described in Organometallics 6, 232-241 (1987).

In US Serial No. 8,800, filed January 30, 1987 (published in equivalent form as EP 277,004) there are disclosed certain bis(cyclopentadienyl) metal compounds formed by reacting a bis(cyclopentadienyl) metal complex with salts of Bronsted acids containing a non-coordinating compatible anion. The reference discloses the fact that such complexes are usefully employed as catalysts in the polymerization of olefins. The foregoing catalysts are not considered to be particularly effective olefin polymerization catalysts.

Previous attempts to prepare copolymers of vinylidene aromatic monomers and α-olefins, in particular copolymers of styrene and ethylene, have either failed to obtain substantial incorporation of the vinylidene aromatic monomer or else have achieved polymers of [illegible] molecular weight. In Polymer Bulletin, 20, 237-241 (1988) there is disclosed a random copolymer of styrene and ethylene containing 1 mole percent styrene incorporated therein. The reported polymer yield was 8.3×10^{-4} grams of polymer per micromole titanium employed.

It has now been discovered that previously known addition polymerization catalysts are incapable of high activity and polymerization of numerous monomers because they lack constrained geometry.

In one aspect the present invention relates to a metal coordination complex having constrained geometry. More particularly it relates to such coordination complexes that are usefully employed in combination with activating cocatalyst compounds or mixtures of compounds to form a catalytic system usefully employed in the polymerization of addition polymerizable monomers, especially ethylenically unsaturated monomers.

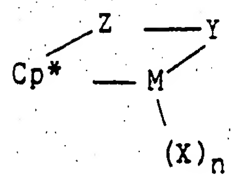
In another aspect the present invention relates to a process for preparing certain components of the above metal coordination complexes having constrained geometry and to the precursor compounds necessary therefor.

In yet another aspect the present invention relates to a process for preparing addition polymers, especially homopolymers and copolymers of olefins, diolefins, hindered aliphatic vinyl monomers, vinylidene aromatic monomers and mixtures of the foregoing and to the resulting polymer products.

According to the present invention there is provided a metal coordination complex comprising a metal of group 3 (other than scandium), 4-10 or the lanthanide series of the Periodic Table of the Elements and a delocalized π-bonded moiety substituted with a constrain-inducing moiety, said complex having a constrained geometry about the metal atom such that the angle at the metal between the centroid of the delocalized, substituted π-bonded moiety and the center of at least one remaining substituent is less than such angle in a comparative complex differing only in that said constrain-inducing substituent is replaced by hydrogen, and provided further that for such complexes comprising more than one delocalized, substituted Π-bonded moiety, only one thereof for each metal atom of the complex is a cyclic, delocalized, substituted Π-bonded moiety.

Said metal coordination complexes are referred to hereinafter as "metal coordination complexes of the invention".

In addition there is provided a metal coordination complex corresponding to the formula:



I

wherein:

M is a metal of Group 3 (other than scandium), 4-10, or the lanthanide series of the Periodic Table of the Elements;

Cp* is a cyclopentadienyl or substituted cyclopentadienyl group bound in an η bonding mode to M;

Z is a moiety comprising boron, or a member of Group 14 of the Periodic Table of the Elements, and optionally sulfur or oxygen, said moiety having up to 20 non-hydrogen atoms, and optionally Cp* and Z together form a fused ring system;

X each occurrence is an anionic ligand group or neutral Lewis base ligand group having up to 30 non-hydrogen atoms;

n is 0, 1, 2, 3, or 4 depending on the valence of M; and

Y is an anionic or nonanionic ligand group bonded to Z and M comprising nitrogen, phosphorus, oxygen or sulfur and having up to 20 non-hydrogen atoms, optionally Y and Z together form a fused ring system.

There is also provided according to the present invention a process for preparing a metal coordination complex corresponding to the foregoing Formula I comprising contacting a metal compound of the formula MX_{n+2} or a coordinated adduct thereof with a dianionic salt compound corresponding to the formula:

$(L^{+x})_y(Cp^*\text{-}Z\text{-}Y)^{-2}$ (II) or $((LX'')^{+x})_y(Cp^*\text{-}Z\text{-}Y)^{-2}$ (III)

wherein:

L is a metal of group 1 or 2 of the periodic table of the elements,

X" is fluoro, chloro, bromo, or iodo,

x and y are either 1 or 2 and the product of x and y equals 2, and M, X, Cp, and Y are as previously defined in an inert, aprotic solvent.

Further there is provided a process for preparing a metal coordination complex corresponding to the foregoing Formula I comprising the steps of:

A) contacting a metal compound of the formula MX_{n+1} or a coordinated adduct thereof with a dianionic salt compound corresponding to the formulas II or III in an inert, aprotic solvent; and

B) oxidizing the metal to a higher oxidation state by contacting the reaction product of step A) with a noninterfering oxidizing agent.

There is also provided a catalyst useful in addition polymerizations comprising the following components:

a) a metal coordination complex of the invention, preferably corresponding to Formula I, and an activating cocatalyst.

Further according to the present invention there is provided a polymerization process comprising contacting one or more addition polymerizable monomers under addition polymerization conditions with a catalyst comprising:

a) a metal coordination complex of the invention, preferably corresponding to Formula I, and an activating cocatalyst.

Further still according to the present invention there is provided a polymer comprising in polymerized form one or more addition polymerizable monomers prepared by contacting an addition polymerizable monomer or mixture thereof under addition polymerization conditions with a catalyst comprising:

a) a metal coordination complex of the invention, preferably corresponding to Formula I, and an activating cocatalyst.

In still further embodiments there are provided EIPE polymers which are highly elastic, interpolymers of ethylene and one or more olefins other than ethylene.

In addition there are provided pseudo-random interpolymers of an α-olefin, particularly ethylene and a vinylidene aromatic monomer, a hindered aliphatic vinylidene monomer, or a mixture thereof.

The complexes of the invention are usefully employed as catalysts for addition polymerization process s to prepar polymers that ar useful as molded articles, films for packaging applications, and foams for cushioning applications; and in the modification of synth tic and naturally occurring resins. The complexes may also be used as catalysts for hydrogenations, catalytic cracking processes, and in other industrial applications.

Figures 1-5 are computer generated models of constrained geometry complexes of the ... ention based on single crystal X-ray data.

Figures 6 and 7 are computer generated models of metal complexes based on single crystal X-ray data showing less constraint than those of Figures 1-5.

Figures 8-13 illustrate calculated and observed distribution of styrene, ethylene and reversed styrene units in ethylene/styrene copolymers observing pseudo-random incorporation rules according to the invention.

Figure 14 illustrates lack of agreement between calculated and observed distribution of styrene, ethylene and reversed styrene units in ethylene/styrene copolymers if completely random incorporation rules are followed.

Figure 15 shows typical rheology curves of a EIPE resin according to the present invention. Shown are complex viscosity, η^*, and tan δ curves as a function of shear rate, for the resin.

Figure 16 shows a typical curve of elastic modulus versus melt index for the EIPE resins of the present invention.

Figure 17 shows typical rheology curves of a conventionally prepared polyethylene resin. Shown are complex viscosity, η^*, and tan δ curves as a function of shear rate, for the resin.

By use of the term "delocalized Π-bonded moiety" is meant an unsaturated organic moiety, such as those comprising ethylenic or acetylenic functionality, wherein the Π-electrons thereof are donated to the metal to form a bond. Examples include alkene-, alkenyl-, alkyne-, alkynyl-, allyl-, polyene-, and polyenyl-moieties as well as unsaturated cyclic systems.

By use of the term "constrained geometry" herein is meant that the metal atom is forced to greater exposure of the active metal site because of one or more substituents on the delocalized Π-bonded moiety. Preferably the delocalized Π-bonded moiety is a cyclopentadienyl or substituted cyclopentadienyl group forming a portion of a ring structure wherein the metal is both bonded to an adjacent covalent moiety and is held in association with the delocalized Π-bonded moiety through η^5 bonds. It is understood that each respective bond between the metal atom and the constituent atoms of the delocalized Π-bonded moiety need not be equivalent. That is the metal may be symmetrically or unsymmetrically Π-bound to the Π-bonded moiety.

The geometry of the active metal site is further defined as follows. The centroid of the Π-bonded moiety may be defined as the average of the respective X, Y, and Z coordinates of the atomic centers forming the Π-bonded moiety. The angle, Θ, formed at the metal center between the centroid of the Π-bonded moiety and each other ligand of the metal complex may be easily calculated by standard techniques of single crystal X-ray diffraction. Each of these angles may increase or decrease depending on the molecular structure of the constrained geometry metal complex. Those complexes wherein one or more of the angles, Θ, is less than in a similar, comparative complex differing only in the fact that the constrain-inducing substituent is replaced by hydrogen have constrained geometry for purposes of the present invention. Preferably one or more of the above angles, Θ, decrease by at least 5 percent more preferably 7.5 percent compared to the comparative complex. Highly preferably, the average value of all bond angles, Θ, is also less than in the comparative complex. Most preferably the metal coordination complex having constrained geometry is in the form of a ring structure, ie. the constrain-inducing substituent is part of a ring system which includes the metal.

Preferably, monocyclopentadienyl metal coordination complexes of group 4 or lanthanide metals according to the present invention have constrained geometry such that the smallest angle, Θ, is less than 115°, more preferably less than 110°, most preferably less than 105°.

Illustrative atomic arrangements of complexes as determined from single crystal X-ray diffraction values are shown in Figures 1-7.

Figure 1 shows the single-crystal X-ray crystallographically determined structure of (4-methylphenylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride. The angle formed by the centroid of the cyclopentadienyl ring (C2, C3, C5, C7 and C9), the titanium atom (TI1), and the nitrogen atom (N14) is 105.7°.

Figure 2 shows the single-crystal X-ray crystallographically determined structure of (t-butyl amido)-dimethyl(tetramethyl-η^5-cyclopentadienyl)silanezirconium dimethyl. The angle formed by the centroid of the cyclopentadienyl ring (C2, C3, C3*, C5, and C5*), the zirconium atom (ZR1), and the nitrogen atom (N9) was determined to be 102.0°.

Figure 3 shows the single-crystal X-ray crystallographically determined structure of (phenyl amido)-dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride. The angle form d by the centroid of th cyclopentadienyl ring (C2, C3, C5, C7, and C9), the titanium atom (TI1), and the nitrogen atom (N14) was determined to be 106.1°.

Figure 4 shows the single-crystal X-ray crystallographically determined structure of (tert-butyl amido)-dimethyl(η^5-cyclopentadienyl)silanezirconium dichloride. The structure shows that this molecule crystallizes as a dimer with 2 bridging chlorides. The angle formed by the centroid of the cyclopentadienyl ring (C2, C3, C4, C5, and C6), the zirconium atom (ZR1), and the nitrogen atom (N10), or the angle formed by the centroid of the cyclopentadienyl ring (C102, C103, C104, C105, and C106), the zirconium atom (ZR101), and the nitrogen atom (N110) were determined to be 99.1°.

Figure 5 shows the single-crystal X-ray crystallographically determined structure of (t-butyl amido)-dimethyl(tetramethyl-η^5-cyclopentadienyl)silanezirconium dichloride. The angle formed by the centroid of the cyclopentadienyl ring (C1, C2, C3, C4, and C5) , the zirconium atom (ZR), and the nitrogen atom (N) was determined to be 102.0°.

Figure 6 shows the single-crystal X-ray crystallographically determined structure of (t-butyl amido)-tetramethyl(tetramethyl-η^5-cyclopentadienyl)disilanezirconium dichloride. The relatively long disilyl linking group that connects the cyclopentadienyl ring to the nitrogen atom of the amide ligand allows the nitrogen atom to be less constrained. The angle formed by the centroid of the cyclopentadienyl ring (C2, C3, C5, C7, and C9), the zirconium atom (ZR1), and the nitrogen atom (N17) was determined to be 118.0°. The activity of this catalyst towards olefin polymerization is considerably diminished relative to the analogous monosilane linking group in (tert-butyl amido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanezirconium dichloride (Figure 5).

Figure 7 shows the single-crystal X-ray crystallographically determined structure of (t-butyl amido)-tetramethyl(tetramethyl-η^5-cyclopentadienyl)disilanetitanium dichloride. The relatively long disilyl linking group that connects the cyclopentadienyl ring to the nitrogen atom of the amide ligand allows the nitrogen atom to be less constrained. The angle formed by the centroid of the cyclopentadienyl ring (C2, C3, C5, C7, and C9), the titanium atom (TI1), and the nitrogen atom (N17) was determined to be 120.5°. Accordingly, the activity of this catalyst towards olefin polymerization is considerably diminished relative to the analogous monosilane linking group in (t-butyl amido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride.

The term "activating cocatalyst" as used herein refers to a secondary component of the catalyst able to cause the metal-containing complex to become effective as an addition polymerization catalyst or alternatively to balance the ionic charge of a catalytically activated species. Examples of the foregoing activating cocatalysts for use herein include aluminum compounds containing an Al-O bond such as the alkylaluminoxanes, especially methylaluminoxane; aluminum alkyls; aluminum halides; aluminum alkylhalides; Lewis acids; ammonium salts; noninterfering oxidizing agents, ie. silver salts, ferrocenium ions, etc.; and mixtures of the foregoing.

Particular techniques for the preparation of aluminoxane type compounds by contacting an aluminum alkyl compound with an inorganic salt containing water of crystalization are disclosed in USP 4,542,119. In a particularly preferred embodiment an aluminum alkyl compound is contacted with a regeneratable water-containing substance such as hydrated alumina, silica, or other substance. A process for preparing aluminoxane employing such regeneratable substance is disclosed in EP 338,044.

Additional suitable activating cocatalysts include compounds corresponding to the formula:

$AlR_nX''_{3-n}$

wherein:

R is each occurrence C_{1-10} alkyl or aralkyl;

X'' is halogen; and

n is 1, 2 or 3.

Most preferably such cocatalysts are trialkyl aluminum compounds, particularly triethyl aluminum.

"Addition polymerizable monomers" include for example ethylenically unsaturated monomers, acetylenic compounds, conjugated or nonconjugated dienes, polyenes, carbon monoxide, etc. Preferred monomers include the C_{2-10} α-olefins especially ethylene, propylene, isobutylene, 1-butene, 1-hexene, 4-methyl-1-pentene, and 1-octene. Other preferred monomers include styrene, halo- or alkyl substituted styrene, vinyl chloride, acrylonitrile, methyl acrylate, methylmethacrylate, tetrafluoroethylene, methacrylonitrile, vinylidene chloride, vinylbenzocyclobutane, and 1,4-hexadiene.

By the term "hindered aliphatic vinylidene compounds" is meant addition polymerizable vinylidene monomers corresponding to the formula:

$CG_2=CG'R''$

wherein R'' is an sterically bulky, aliphatic substituent of up to 20 carbons, G independently each occurrenc is hydrogen or methyl, and G' ind pendently each occurrenc is hydrogen or methyl or alternatively G' and R'' together form a ring system. By the term "sterically bulky" is meant that the monomer bearing this substituent is normally incapable of addition polymerization by standard Ziegler-Natta

polymerization catalysts at a rate comparable with ethylene polymerizations. Preferred hindered aliphatic vinylidene compounds ar monomers in which on of the carbon atoms bearing ethylenic unsaturation is tertiary or quaternary substituted. Examples of such substituents include cyclic aliphatic groups such as cyclohexane, cyclohexene, cyclooctene, or ring alkyl or aryl substituted derivatives thereof, tert-butyl, norbornyl, etc. Most preferred hindered aliphatic vinylidene compounds are the various isomeric vinyl-ring substituted derivatives of cyclohexene and substituted cyclohexenes, and 5-ethylidene-2-norbornene. Especially suitable are 1-, 3-, and 4-vinylcyclohexene.

By the term "hindered vinylidene compound" is meant addition polymerizable vinylidene monomers corresponding to the formula:

$CG_2 = CGR'''$

wherein R‴ is R″ or an aryl substituent of up to 20 carbons, and G and G′ are as previously defined. For example, in addition to hindered aliphatic vinylidene compounds, hindered vinylidene compounds also include the vinylidene aromatic monomers.

By the term "vinylidene aromatic monomers" is meant addition polymerizable compounds corresponding to the formula:

wherein G independently each occurrence is hydrogen or methyl and Ph is phenyl, or a halo- or C_{1-4} alkyl-

$CG_2 = C(G)\text{-}Ph$

substituted phenyl group. Preferred vinylidene aromatic monomers are monomers corresponding to the above formula wherein G each occurrence is hydrogen. A most preferred vinylidene aromatic monomer is styrene.

By the term "α-olefin" is meant ethylene and the C_{3-10} olefins having ethylenic unsaturation in the α-position. Preferred α-olefins are ethylene, propylene, 1-butene, isobutylene, 4-methyl-1-pentene, 1-hexene, and 1-octene, and mixtures thereof.

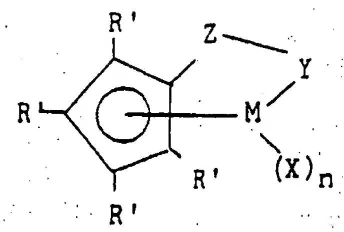
As used herein all reference to the Periodic Table of the Elements and groups thereof shall be to the version of the table published by the Handbook of Chemistry and Physics, CRC Press, 1987, utilizing the IUPAC system for naming groups.

Preferred metal coordination complexes are group 4 or Lanthanide based complexes. Further preferred complexes are those comprising a delocalized η^5 bonded group which is a cyclopentadienyl or substituted cyclopentadienyl group which forms a ring structure with the metal atom. Preferred delocalized Π-bonded moieties are cyclopentadienyl-, indenyl-, and fluorenyl groups, and saturated derivatives thereof which form a ring structure with the metal atom. Each carbon atom in the cyclopentadienyl radical may be substituted or unsubstituted with the same or a different radical selected from the group consisting of hydrocarbyl radicals, substituted-hydrocarbyl radicals wherein one or more hydrogen atoms is replaced by a halogen atom, hydrocarbyl-substituted metalloid radicals wherein the metalloid is selected from Group 14 of the Periodic Table of the Elements, and halogen radicals. In addition two or more such substituents may together form a fused ring system. Suitable hydrocarbyl and substituted-hydrocarbyl radicals, which may be substituted for at least one hydrogen atom in the cyclopentadienyl radical, will contain from 1 to 20 carbon atoms and include straight and branched alkyl radicals, cyclic hydrocarbon radicals, alkyl-substituted cyclic hydrocarbon radicals, aromatic radicals and alkyl-substituted aromatic radicals. Suitable organometalloid radicals include mono-, di- and trisubstituted organometalloid radicals of Group 14 elements wherein each of the hydrocarbyl groups contain from 1 to 20 carbon atoms. More particularly, suitable organometalloid radicals include trimethylsilyl, triethylsilyl, ethyldimethylsilyl, methyldiethylsilyl, phenyldimethylsilyl, methyldiphenylsilyl, triphenylsilyl, triphenylgermyl, trimethylgermyl and the like.

In the previously disclosed Formula I, suitable anionic ligand groups, X, are illustratively selected from the group consisting of hydride, halo, alkyl, silyl, germyl, aryl, amide, aryloxy, alkoxy, phosphide, sulfide, acyl, pseudo halides such as cyanide, azide, etc., acetylacetonate, etc., or a combination thereof.

As previously mentioned, the complexes according to the present invention preferably comprise structures having altered or enhanced catalytic activity at the metal site when the complex is combined with a cocatalyst. In this regard electron donating substituents have been found to improve the catalytic properties of the complexes. That is, even though certain of the complexes do not possess constrained geometry, the same nevertheless possess catalytic properties, alone or in combination with activating substances.

A highly preferred metal coordination complex corresponds to the formula:



wherein R′ each occurrence is hydrogen or a moiety selected from the group consisting of alkyl, aryl, silyl, germyl, cyano, halo and combinations thereof (e.g. alkaryl, aralkyl, silyl substituted alkyl, silyl substituted aryl, cyanoalkyl, cyanoaryl, haloalkyl, haloaryl, halosilyl, etc.) having up to 20 non-hydrogen atoms, or an adjacent pair of R′ groups form a hydrocarbyl ring fused to the cyclopentadienyl moiety;

X each occurrence is hydride or a moiety selected from the group consisting of halo, alkyl, aryl, silyl, germyl, aryloxy, alkoxy, amide, siloxy and combinations thereof (e.g. alkaryl, aralkyl, silyl, substituted alkyl, silyl substituted aryl, aryloxy alkyl, aryloxyaryl, alkoxyalkyl, alkoxyaryl, amidoalkyl, amidoaryl, siloxyalkyl, siloxyaryl, amidosiloxyalkyl, haloalkyl, haloaryl, etc.) having up to 20 non-hydrogen atoms and neutral Lewis base ligands having up to 20 non-hydrogen atoms;

Y is -O-, -S-, -NR*-, -PR*-, or a neutral two electron donor ligand selected from the group consisting of OR*, SR*, NR^*_2, or PR^*_2;

M is as previously defined; and

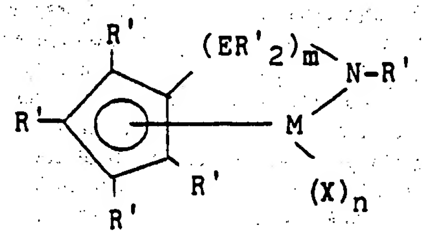
Z is SiR^*_2, CR^*_2, $SiR^*_2SiR^*_2$, $CR^*_2CR^*_2$, CR*=CR*, $CR^*_2SiR^*_2$, GeR^*_2, BR*, BR^*_2; wherein:

R* each occurrence is hydrogen or a moiety selected from the group consisting of alkyl, aryl, silyl, halogenated alkyl, halogenated aryl groups and combinations thereof (e.g. aralkyl, alkaryl, haloalkaryl and haloaralkyl) having up to 20 non-hydrogen atoms, or two or more R* groups from Y, Z, or both Y and Z form a fused ring system.

It should be noted that whereas formula I and the following formulas indicate a cyclic structure for the catalysts, when Y is a neutral two electron donor ligand, the bond between M and Y is more accurately referred to as a coordinate-covalent bond. Also, it should be noted that the complex may exist as a dimer or higher oligomer.

Further preferably, at least one of R′, Z, or R* is an electron donating moiety. Thus, highly preferably Y is a nitrogen or phosphorus containing group corresponding to the formula -N(R″″)- or -P(R″″)-, wherein R″″ is C_{1-10} alkyl or aryl, ie. an amido or phosphido group.

Most highly preferred complex compounds are amidosilane- or amidoalkanediyl- compounds corresponding to the formula:



wherein:

M is titanium, zirconium or hafnium, bound in an η^5 bonding mode to the cyclopentadienyl group;

R′ each occurrence is hydrogen or a moiety selected from the group consisting of silyl, alkyl, aryl and combinations thereof having up to 10 carbon or silicon atoms or an adjacent pair of R′ groups form a hydrocarbyl ring fused to the cyclopentadienyl moiety;

E is silicon or carbon;

X each occurrence is hydride, halo, alkyl, aryl, aryloxy or alkoxy of up to 10 carbons;

m is 1 or 2; and

n is 1 or 2 depending on the valence of M.

Examples of the above most highly preferred metal coordination compounds include compounds wherein the R′ on th amido group is methyl, ethyl, propyl, butyl, pentyl, hexyl, (including isomers), norbornyl, benzyl, phenyl, etc.; the cyclopentadienyl group is cyclopentadienyl, indenyl, tetrahydroindenyl, fluorenyl, octahydrofluorenyl, etc.; R′ on the foregoing cyclopentadienyl groups each occurrence is hy-

drogen, methyl, ethyl, propyl, butyl, pentyl, hexyl, (including isomers), norbornyl, benzyl, phenyl, etc.; and X is chloro, bromo, iodo, methyl, ethyl, propyl, butyl, pentyl, hexyl, (including isomers), norbornyl, benzyl, phenyl, etc. Specific compounds include: (tert-butylamido)(tetramethyl-η^5-cyclopentadienyl)-1,2-ethanediylzirconium dichloride, (tert-butylamido)(tetramethyl-η^5-cyclopentadienyl)-1,2-ethanediyltitanium dichloride, (methylamido)(tetramethyl-η^5-cyclopentadienyl)-1,2-ethanediylzirconium dichloride, (methylamido)-(tetramethyl-η^5-cyclopentadienyl)-1,2-ethanediyltitanium dichloride, (ethylamido)(tetramethyl-η^5-cyclopentadienyl)-methylenetitanium dichloride, (tert-butylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)-silanetitanium dichloride, (tert-butylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl) silanezirconium dibenzyl, (benzylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride, (phenylphosphido)-dimethyl(tetramethyl-η^5-cyclopentadienyl)silanezirconium dibenzyl, and the like.

The complexes can be prepared by contacting the metal reactant and a group I metal derivative or Grignard derivative of the cyclopentadienyl compound in a solvent and separating the salt byproduct. Suitable solvents for use in preparing the metal complexes are aliphatic or aromatic liquids such as cyclohexane, methylcyclohexane, pentane, hexane, heptane, tetrahydrofuran, diethyl ether, C_{1-4} alkyl ethers of mono- or diethylene glycol, C_{1-4} alkyl ethers of mono-or dipropylene glycol, benzene, toluene, xylene, ethylbenzene, etc., or mixtures thereof.

In a preferred embodiment, the metal compound is MX_{n+1}, ie. M is in a lower oxidation state than in the corresponding compound, MX_{n+2} and the oxidation state of M in the desired final complex. A noninterfering oxidizing agent may thereafter be employed to raise the oxidation state of the metal. The oxidation is accomplished merely by contacting the reactants utilizing solvents and reaction conditions used in the preparation of the complex itself. By the term "noninterfering oxidizing agent" is meant a compound having an oxidation potential sufficient to raise the metal oxidation state without interfering with the desired complex formation or subsequent polymerization processes. A particularly suitable noninterfering oxidizing agent is AgCl.

In order to assist in the handling of the metal compounds employed in the present process corresponding to the formula MX_{n+2}, it may be beneficial first to form a solid adduct thereof by the use of a suitable coordinating agent according to well known techniques in the art. For example, whereas titanium tetrachloride is a fuming liquid which is difficult to handle, one may first form an adduct of $TiCl_4$ with an ether, tertiary amine, tertiary phosphine or other basic nonprotic compound. The resulting solids may be more easily handled. A preferred coordinating adduct is tetrahydrofuran.

The reactions employed in preparing the metal complex may be conducted either heterogeneously or homogeneously. That is, the various reactants or the resulting product need not be substantially soluble in the solvent mixture. Generally the reactants are contacted under an inert atmosphere for a time from several minutes to several days. Agitation may be employed if desired. The temperature of the reaction is generally from -90 °C to 150 °C, preferably from -20 °C to 70 °C.

Suitable catalysts for use according to the present invention are prepared by combining the metal coordination compound and activating cocatalyst compound in any order and in any suitable manner. Preferably the ratio of the coordination complex and cocatalyst on a molar basis is from 1:0.1 to 1:10,000. It will, of course, be appreciated that the catalyst system may also be formed *in situ* if the components thereof are added directly to the polymerization process and a suitable solvent or diluent, including condensed monomer, is used in said polymerization process. Suitable solvents include toluene, ethylbenzene, alkanes and mixtures thereof. In certain cases the catalysts may be isolated from solution and retained under inert atmosphere prior to use. The catalysts' components are sensitive to both moisture and oxygen and should be handled and transferred in an inert atmosphere such as nitrogen, argon or helium or under vacuum.

The polymerization is usually conducted according to known techniques for Ziegler-Natta or Kaminsky-Sinn type polymerizations. That is, the monomer(s) and catalyst are contacted at a temperature from -30 °C to 250 °C, at reduced, elevated or atmospheric pressures. The polymerization is conducted under an inert atmosphere which may be a blanketing gas such as nitrogen, argon, hydrogen, ethylene, etc. or under vacuum. Hydrogen may additionally be utilized in the control of molecular weight through chain termination as is previously known in the art. The catalyst may be used as is or supported on a suitable support such as alumina, $MgCl_2$ or silica to provide a heterogeneous supported catalyst. A solvent may be employed if desired. Suitable solvents include toluene, ethylbenzene, and excess vinylidene aromatic or olefin monomer. The reaction may also be conducted under solution or slurry conditions, in a suspension utilizing a perfluorinated hydrocarbon or similar liquid, in the gas phase, ie. utilizing a fluidized bed r actor, or in a solid phase powder polymerization. A catalytically effective amount of the present catalyst and cocatalyst are any amounts that successfully result in formation of polymer. Such amounts may be readily determined by the routine experimentation by the skilled artisan. Preferred amounts of catalyst and cocatalyst are

sufficient to provide an equivalent ratio of addition polymerizable monomer:catalyst of from $1X10^{10}$:1 to 100:1, preferably from $1X10^{8}$:1 to 500:1, most preferably $1x10^{6}$:1 to 1000:1. The cocatalyst is generally utilized in an amount to provide an equivalent ratio of cocatalyst:catalyst from 10,000:1 to 0.1:1, preferably from 1,000:1 to 1:1.

It is to be understood that the metal complex may undergo various transformations or form intermediate species prior to and during the course of a polymerization. Thus other precursors could possibly be conceived to achieve the same catalytic species as are herein envisioned without departing from the scope of the present invention.

The resulting polymeric product is recovered by filtering or other suitable technique. Additives and adjuvants may be incorporated in the polymers of the present invention in order to provide desirable characteristics. Suitable additives include pigments, UV stabilizers, antioxidants, blowing agents, lubricants, plasticizers, photosensitizers, and mixtures thereof.

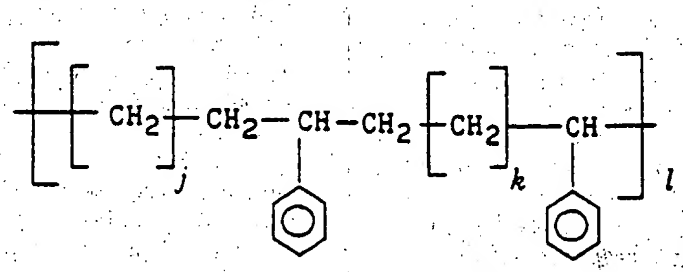
In the preparation of copolymers containing vinylidene aromatic or hindered aliphatic vinyl monomers it is desirable that a comonomer that is an α-olefin that is not particularly sterically hindered also be employed. Without wishing to be bound by any particular theory of operation, it is believed this is because the active site becomes crowded with the incorporation of the hindered vinyl compound making it unlikely that another hindered vinyl compound could enter into the polymerization as the next monomer in the sequence. After the incorporation of one or more olefins other than a hindered vinyl compound the active site once again becomes available for inclusion of a hindered vinyl monomer. On a limited basis however, the vinylidene aromatic monomer or sterically hindered vinyl monomer may insert into the polymer chain in reverse order, ie. so as to result in two methylene groups between the substituted polymer backbone moiety.

Preferably such polymers possess a Mw of greater than 13,000, more preferably greater than 20,000 and most preferably greater than 30,000. Also preferably such polymers possess a melt index (I_2), ASTM D-1238 Procedure A, condition E, of less than 125, more preferably from 0.01 - 100 and most preferably from 0.1 to 10.

Due to the use of the previously mentioned catalyst system comprising a coordination complex having constrained geometry, copolymers may be prepared that incorporate relatively bulky or hindered monomers in substantially random manner at low concentrations, and at higher concentrations according to an ordered insertion logic. The copolymers of α-olefins, especially ethylene and a hindered aliphatic vinylidene compound or vinylidene aromatic monomer can further be described as "pseudo-random". That is, the copolymers lack well defined blocks of either monomer, however the respective monomers are limited to insertion according to certain rules.

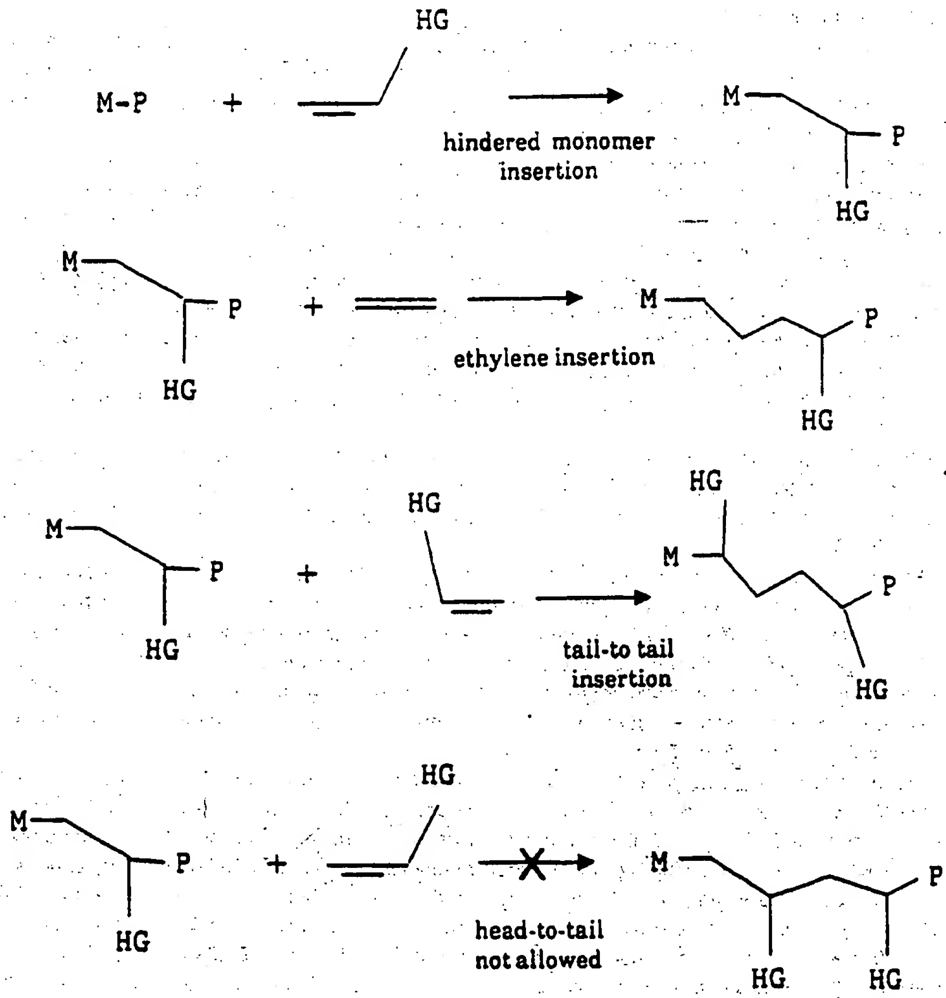
These rules were deduced from certain experimental details resulting from an analysis of the polymers. The polymers were analyzed by ^{13}C NMR spectroscopy at 130 °C with a Varian VXR-300 spectrometer at 75.4 MHz. Samples of 200 to 250 mg polymer were dissolved in 15 mL of hot o-dichlorobenzene/1,1,2,2-tetrachloroethane-d_2 (approximately 70/30, v/v) which was approximately 0.05 M in chromium (III) tris-(acetylacetonate) and a portion of the resulting solution was added to a 10 mm NMR tube. The following parameters and conditions were used: spectral width, 16,500 Hz; acquisition time 0.090 s; pulse width, 36°; delay, 1.0 s with the decoupler gated off during the delay,; FT size 32K; number of scans, >30,000; line broadening, 3Hz. Spectra, as recorded were referenced to tetrachloroethane-d_2 (δ73.77 ppm, TMS scale).

Therefor, without wishing to be bound by any particular theory, the results of the foregoing experimental procedures indicate that a particular distinguishing feature of pseudo-random copolymers is the fact that all phenyl or bulky hindering groups substituted on the polymer backbone are separated by 2 or more methylene units. In other words, the polymers comprising a hindered monomer of the present invention can be described by the following general formula (using styrene as the hindered monomer for illustration):



where j, k, and $l \geqq 1$

In further explanation of the foregoing experimental and theoretical results, and without wishing to be bound by any particular theory it can be concluded that during the addition polymerization reaction employing the present catalysts, if a hindered monomer is inserted into the growing polymer chain, the next monomer inserted must be ethylene or a hindered monomer which is inserted in an inverted or "tail-to-tail" fashion. This is illustrated below for a hindered vinyl monomer where M is the catalyst metal center, HG is a hindering group, and P is the growing polymer chain:



During the polymerization reaction, ethylene may be inserted at any time. After an inverted or "tail-to-tail" hindered monomer insertion, the next monomer must be ethylene, as the insertion of another hindered monomer at this point would place the hindering substituent closer together than the minimum separation as described above. A consequence of these polymerization rules is the catalysts of this invention do not homopolymerize styrene to any appreciable extent, while a mixture of ethylene and styrene is rapidly polymerized and may give high styrene content (up to 50 mole percent styrene) copolymers.

As a further illustration of the description of the α-olefin/hindered monomer copolymer of the present invention, a computer model of the polymerization reaction was used to calculate the expected ^{13}C NMR spectrum of the polymer product. The computer program utilized a random number generator to select either α-olefin or hindered monomer to be inserted into a growing polymer chain, then calculated the number of each type of ^{13}C NMR signals r sulting from that insertion. Polymers were computer generated by repeating this process for 10,000 or more monomer insertions, and the resulting calculated ^{13}C NMR spectrum was compared to actual experimental ^{13}C NMR spectra for pseudo-random ethylene/styrene copolymers of the inv ntion.

Computer simulations of the polymer and resulting ^{13}C NMR spectra of the calculated pseudo-random

ethylene/styrene copolymers were performed using the constraint that if styrene monomer were inserted into the growing polymer chain, the next monomer inserted must be ethylene or a styrene which is inserted in an inverted or "tail-to-tail" fashion. Optimum fits between experimental and calculated spectra were obtained if approximately 15 percent of the styrene insertions are in the "tail-to-tail" manner. The observed and calculated ^{13}C NMR spectra for such pseudo-random ethylene/styrene copolymers containing 1.4, 4.8, 9.0, 13, 37, and 47 mole percent styrene are shown in figures 8-13. In each case, the observed and calculated spectra are in excellent agreement.

Computer simulation of the polymer and resulting ^{13}C NMR spectra of completely random α-olefin/hindered monomer copolymers were then performed using no constraints on hindered monomer insertion. In other words, the hindered monomer was allowed to insert into the growing polymer chain after a previous hindered monomer insertion if the random number generator selected hindered monomer as the next monomer to be inserted. The calculated spectra for these completely random copolymers do not agree with the observed ^{13}C NMR spectra, as shown in figure 14 for a 37 mole percent styrene containing ethylene/styrene copolymer.

Prior to polymerization according to the present process the monomers and solvents, if any, may be purified by vacuum distillation, and/or contacted with molecular sieves, silica, or alumina to remove impurities. In addition, reactive blanking agents, such as trialkylaluminum compounds, alkali metals and metal alloys, especially Na/K, may be used to remove impurities.

Suitable vinylidene aromatic monomers which may be employed according to the present invention include styrene as well as α-methyl styrene, the C_1-C_4 alkyl- or phenyl- ring substituted derivatives of styrene, such as ortho-, meta-, and para-methylstyrene, or mixtures thereof, the ring halogenated styrenes, vinylbenzocyclobutanes, and divinylbenzene. A preferred vinylidene aromatic monomer is styrene.

In the polymerization of vinylidene aromatic monomers or hindered aliphatic vinylidene compounds and olefins the monomers are preferably combined in a proportion so as to achieve a vinylidene aromatic monomer (or hindered aliphatic vinylidene compound) content of at least 1.0 mole percent in the resulting polymer more preferably from 1.5 to less than 50 mole percent, highly preferably 5.0 to 48 mole percent, and most preferably from more than 8.0 up to 47 mole percent. Preferred operating conditions for such polymerization reactions are pressures from atmospheric to 1000 atmospheres and temperatures from 30° C to 200° C. Polymerizations at temperatures above the autopolymerization temperature of the respective monomers may contain small amounts of homopolymer polymerization products resulting from free radical polymerization.

Certain of the polymers prepared according to the present invention, especially copolymers of ethylene and an α-olefin other than ethylene, are characterized by unique rheological properties. In particular, it has been found that the polymers (hereinafter called Elastic Polyethylenes or ElPEs) are less Newtonian than conventionally prepared linear polyethylene resins of similar olefin content. The polymers also have higher elastic modulus particularly at high melt indices compared to such conventional polymers. This property makes the resin especially useful in the formation of films, foams and fabricated articles, for example by blow molding techniques. The above phenomenon is more particularly defined by reference to Figure 16 wherein complex viscosity, η^* measured in poise at 190° C , is plotted as a function of shear rate, ω, measured in radians per second for a typical ElPE copolymer of ethylene and 1-octene according to the invention. The slope of this curve indicates the melt is highly non-Newtonian. The actual values of η^* and ω utilized in the graph are:

η^*	ω	η^*	ω	η^*	ω
1.962×10^5	0.01000	3.230×10^4	0.2512	1.088×10^4	6.310
1.511×10^5	0.01585	2.713×10^4	0.3981	9.336×10^3	10.000
1.115×10^5	0.02512	2.293×10^4	0.6310	7.964×10^3	15.850
8.292×10^4	0.03981	1.966×10^4	1.0000	6.752×10^3	25.120
6.322×10^4	0.06310	1.701×10^4	1.5850	5.677×10^3	39.810
4.920×10^4	0.10000	1.464×10^4	2.5120	4.721×10^3	63.100
3.956×10^4	0.15850	1.265×10^4	3.9810	3.854×10^3	100.000

Also plotted in Figure 15 is the tan δ value of the sam EIPE polym r. This value is unitless and is calculated by dividing the viscous modulus valu by the lastic modulus. The actual values of tan δ and ω utilized in the graph are:

tan δ	ω	tan δ	ω	tan δ	ω
0.5526	0.01000	1.243	0.2512	1.718	6.310
0.5231	0.01585	1.381	0.3981	1.677	10.000
0.5771	0.02512	1.543	0.6310	1.620	15.850
0.6597	0.03981	1.615	1.0000	1.552	25.120
0.7971	0.06310	1.690	1.5850	1.475	39.810
0.9243	0.10000	1.729	2.5120	1.398	63.100
1.080	0.15850	1.737	3.9810	1.315	100.000

For improved performance in melt blowing applications preferably the tan δ value is from 0.1 to 3.0 for shear rates between 0.01-100 radian/sec.

A further property of EIPE polymers is illustrated by reference to Figure 16 . The elastic modulus in dynes/cm², G′, at 0.1 radian/sec., and 190 °C for several ethylene/1-octene EIPE resins is plotted as a function of melt index. The resins utilized include those of Examples 11, 12, 14-16, 18-22, 24-26, 30 and 31. The values of melt index and elastic modulus utilized in the graph are as follows:

Melt Index	Elastic Modulus	Melt Index	Elastic Modulus	Melt Index	Elastic Modulus
0.10	98760	3.34	4381	18.42	9669
0.15	35220	5.34	5858	31.2	4516
0.18	35920	6.38	10480	31.53	5012
0.22	14270	10.12	5276	31.69	3238
0.45	11140	10.66	6222	41.02	2972
1.72	3003	16.28	2697	-	-
2.46	10620	16.32	6612	-	-

Typical properties of η^* and ω for a conventionally prepared polyethylene resin are provided in Figure 17 for comparison purposes.

It is readily seen that EIPE resins are characterized by high elastic modulus in the melt. In particular, EIPE resins have a melt index ((I_2), ASTM D-1238 Procedure A, condition E), less than 200, preferably less than 125, most preferably less than 50 and an elastic modulus greater than 1000 dyne/cm², more preferably greater than 2000 dyne/cm². All of the foregoing rheological measurements are performed by standard techniques such as are disclosed in H. A. Barnes et al., Introduction to Rheology, Elsevier, publishing, Inc., 1989. Densities normally range from 0.85 to 0.97 g/ml, preferably from 0.89-0.97 g/ml. Molecular weight distributions (Mw/Mn) are greater than 2.0, preferably from 3.0-10.0. Typically melting points range from 50 °C to 135 °C.

Preferred polymers additionally demonstrate properties of homogeneous polymers as defined in USP 3,845,992, ie. ethylene copolymers having substantially random comonomer distribution within a given molecule and substantially the same ethylene/comonomer ratio between molecules. Polymers produced at elevated polymerization temperatures, especially temperatures greater than 130 °C, may exhibit a heterogeneous melt curve. The polymers of the invention are further marked by high clarity. In particular the polymers have better optical properties, especially lower haze than typical ethylene polymers, making them especially well suited for film and injection molding applications.

In addition those polymers comprising an olefin and a vinylidene aromatic monomer, especially ethylene and styrene, have surprisingly been found to possess elastomeric properties. Thus, such polymers are uniquely suited for use in applications for thermoplastic elastomers such as impact modification of thermoplastic and thermosetting polymers including bitumens; adhesives; elastomeric moldings; etc.

The polymers of the invention may be modified by typical grafting, crosslinking, hydrogenation, functionalizing, or other reactions well known to those skilled in the art. With particular regard to the polymers comprising vinylidene aromatic, vinylcyclohexene, or 1,4-hexadiene functionality, the same may be readily sulfonated or chlorinated to provide functionalized derivatives according to established techniques. Additionally, the vinylcyclohexene based polymers are readily crosslinkable by reaction of the unsaturated ring functionality.

The polymers of the present invention, whether or not further modified, may be blended with synthetic or natural polymers to provide blends having desirable properties. In particular polyethylene, ethylene/α-olefin copolymers, polypropylene, polystyrene, styrene/acrylonitrile copolymers (including rubber modified derivatives thereof), syndiotactic polystyrene, polycarbonate, polyamide, aromatic polyester, polyisocyanate, polyurethane, polyacrylonitrile, silicone, and polyphenyleneoxide polymers may be blended with the polymeric compositions of the present invention. The polymeric modifier is utilized in amounts from 0.1 to 99.0 preferably 0.5 to 50 weight percent.

In a highly preferred embodiment of the invention the polymers containing ethylene and styrene are elastomeric as defined in the definition of an elastomeric substance by ASTM Special Technical Bulletin No. 184 as a substance that can be stretched at room temperature to twice its length and will return to its original length upon release.

In addition to modification of synthetic thermoplastics the present polymers are also usefully employed as modifiers for asphalt or bitumen compositions. Desirably the polymers of styrene/ethylene are utilized in this manner.

The term "bitumen" can generally be defined as mixtures of hydrocarbons of natural or pyrogenous origin or combinations of both, frequently accompanied by their non-metallic derivatives, which may be gaseous, liquid, semi-solid or solid, and which are usually soluble in carbon disulfide. For the purposes of the present invention, bitumen of a liquid, semi-solid or solid nature may be utilized. From a commercial standpoint, bitumen is generally restricted to asphalts and tars and pitches. A listing of various bituminous materials which can be utilized in the present invention include the following:

I. Asphalts

1. Petroleum Asphalts

A. Straight-reduced asphalts

1. Atmospheric or reduced-pressure reduction
2. Solvent precipitated, as with propane

B. Thermal asphalts, as residues from cracking operations on petroleum stocks

C. Air-blown asphalts

1. Straight-blown
2. "Catalytic"-blown

2. Native Asphalts

A. With mineral content below 5 percent

1. Asphaltites such as gilsonite, graphamite, and glance pitch
2. Bermudez and other natural deposits

B. With mineral content over 5 percent

1. Rock asphalts
2. Trinidad and other natural deposits

II. Tars and Derivatives

1. Residua from coke-oven-dried coal tars

A. Coal tars reduced to float grades, as RT (road tar) grades for paving purposes
B. Coal-tar pitches, with reduction carried out to softening-point grades

2. Residua from other pyrogenous distillates as from water-gas, wood, peat, bone, shale, rosin, and fatty acid tars.

As can be readily appreciated by those skilled in the art, the weight average molecular weight of the various bitumens can vary over a very wide range, for example such as from 500 to 10,000. Additionally, the softening point of the various types of asphalt will also vary such as from 50° F to 400° F.

Of the many types of asphalts which may be utilized, petroleum, and native are desired, with petroleum being preferred. Of the petroleum asphalts, the thermal asphalts are preferred.

The amount of bitumen utilized in the compositions of the invention preferably ranges from 65 to 99 parts by weight with preferred amounts ranging from 80 to 98 parts by weight.

Having described the invention the following examples are provided as further illustrative and are not to be construed as limiting. Unless stated to the contrary parts and percentages are based on weight.

Example 1 Preparation of (Tert-butylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silane zirconium dichloride

To 0.443 g (1.90 mmol) $ZrCl_4$ in a flask was added 8 mL diethyl ether, then 15 mL tetrahydrofuran (THF). To the resulting slurry was slowly added a solution of 0.500 g (1.90 mmol) dilithium (tert-butylamido)-dimethyl(tetramethylcyclopentadienyl)silane in 15 mL THF. The resulting yellow solution was stirred for several days. The solvent was removed to give a gummy residue, which was extracted with 5/1 (volume) diethyl ether:pentane and filtered from a white solid. The solvent was removed from the yellow filtrate to give a light-yellow powder. Recrystallization from ether/pentane (5/1) yielded the product ($C_5Me_4(Me_2Si$-N-tert-Bu)$ZrCl_2$) as an off-white crystalline solid. The yield was 0.2207 g (28.2%). Identification was made by ^{13}C and ^1H NMR.

Polymerization

A. Five mL of a 1.009 M solution of methyl aluminoxane (MAO) in toluene was added to a shot tank containing 25 mL of 4-methyl-1-pentene. The catalyst solution was prepared by adding 500 µL of a 0.01172 M solution of $C_5Me_4(Me_2Si$-N-tert-Bu)$ZrCl_2$ in toluene to 2 mL of toluene in a second shot tank. Both shot tanks were sealed, removed from the glove box, and attached to a 600 mL stainless steel pressure vessel. The pressure vessel was evacuated and purged with argon.

The 4-methyl-1-pentene/toluene/MAO solution was added to the pressure vessel and warmed to 89° C under 620 kPa (90 psig) ethylene with stirring. Upon addition of the catalyst solution to the 4-methyl-1-pentene/MAO/ethylene mixture, the ethylene pressure was increased to 1240-1275 kPa (180-185 psig). After 2 hours the solution was cooled to 30° C and vented. The yield of polymer obtained after drying under reduced pressure at 100° C overnight was 10.0 g. ^{13}C NMR analysis of the polymer showed it to be a random copolymer of ethylene with 4-methyl-1-pentene.

B. The polymerization procedure of Polymerization A was essentially repeated except that 50 mL of 1-hexene was used instead of 4-methyl-1-pentene and the catalyst concentration was 0.01012 M in toluene. The catalyst solution was added to the 1-hexene/MAO/ethylene mixture and the ethylene pressure was increased to 1240-1275 kPa (180-185 psig). When the catalyst solution was added the temperature of the reaction climbed to 139° C. After 30 minutes the solution had cooled to 100° C. Heating and ethylene feed were discontinued and the reactor was cooled and vented. The yield of polymer obtained after drying under reduced pressure at 100° C overnight was 36.8 g. ^{13}C NMR analysis of the polymer showed it to be a random copolymer of ethylene with 1-hexene (8 percent on a mole basis).

C. The polymerization procedure of Polymerization A was essentially repeated except that 213 µL of the catalyst solution (0.01172 M in toluene) was used, and 143 mg of solid MAO was used. No additional olefin was added. When th catalyst solution was added to the r actor the temperature increased to 109° C due to the exothermic polymerization reaction. The reaction was halted after 1 hour by cooling and venting the reactor. The yield of polyethylene obtained after drying under reduced pressure at 100° C overnight was 11.0 g.

D. 150 mL of toluene was added to the pressure vessel employed in Polymerization A, followed by 100 g of propylene. A solution of 0.828 g of MAO in 8 mL of toluene was added, followed by 2130 µL of the catalyst solution. The mixture was allowed to react for 3.0 h at 8 °C. The reaction mixture was quenched with acidic methanol, and 0.38 g of a white, tacky material was obtained. ^{13}C NMR analysis of the polymer showed it to be atactic polypropylene.

Example 2 Preparation of (Tert-butylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride

Preparation 1

(a) (Chloro)(dimethyl)(tetramethylcyclopentadi-2,4-enyl)silane

To a solution of 21.5 g (167 mmol) dimethyldichlorosilane in 150 mL THF cooled to -40 °C was slowly added a solution of 8.00 g (55.6 mmol) sodium 1,2,3,4-tetramethylcyclopentadienide in 80 mL THF. The reaction mixture was allowed to warm to room temperature and was stirred overnight. The solvnet was removed, the residue was extracted with pentane and filtered. The pentane was removed under reduced pressure to give the product as a light-yellow oil. The yield was 10.50 g (88.0%). ^1H NMR (C_6D_6) δ 2.89 (s, 1H), 1.91 (s, 6H), 1.71 (s, 6H), 0.14 (s, 6H); ^{13}C NMR (C_6D_6) δ 137.8, 131.5, 56.6, 14.6, 11.4, 0.81.

(b) (Tert-butylamino)(dimethyl)(tetramethylcyclopentadi-2,4-enyl)silane

A solution of 11.07 g (151 mmol) t-butyl amine in 20 mL THF was added during 5 minutes to a solution of 13.00 g (60.5 mmol) (chloro)(dimethyl)(tetramethylcyclopentadienyl)silane in 300 mL THF. A precipitate formed immediately. The slurry was stirred for 3 days, then the solvent was removed, the residue was extracted with pentane and filtered. The pentane was removed under reduced pressure to give the product as a light-yellow oil. The yield was 14.8 g (97.2%). MS: 251 ^1H NMR (C_6D_6) δ 2.76 (s, 1H), 2.01 (s, 6H), 1.84 (s, 6H), 1.09 (s, 9H), 0.10 (s, 6H); ^{13}C NMR (C_6D_6) δ 135.4, 133.2, 57.0, 49.3, 33.8, 15.0, 11.2, 1.3.

(c) Dilithium (tert-butylamido)(dimethyl)-(tetramethylcyclo-pentadienyl)silane

To a solution of 3.000 g (11.98 mmol) (tert-butylamino)(dimethyl)(tetramethylcyclopentadienyl)silane in 100 mL ether was slowly added 9.21 mL of 2.6 M (23.95 mmol) butyl lithium in mixed C_6 alkane solvent. A white precipitate formed and the reaction mixture was stirred overnight, then filtered. The solid was washed several times with ether then dried under reduced pressure to give the product as a white powder. The yield was 3.134 g (99.8%).

(d) (Tert-butylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silane titanium dichloride

0.721 g (3.80 mmol) Of $TiCl_4$ was added to 30 mL frozen (-196 °C) THF. The mixture was allowed to warm to -78 °C (dry ice bath). To the resulting yellow solution was slowly added a solution of 1.000 g (3.80 mmol) dilithium (tert-butylamido)(dimethyl)tetramethylcyclopentadienyl)silane in 30 mL THF. The solution was allowed to warm to room temperature while stirring overnight. The solvent was removed from the resulting very dark solution. The residue was extracted with pentane and filtered. Cooling in a freezer caused the separation of a very soluble dark reddish-brown material from a light yellow-green crystalline solid. The solid was filtered out and recrystallized from pentane to give the olive-green product. The yield was 0.143 g, 10.2%. ^1H NMR (C_6D_6) δ 2.00 (s, 6H), 1.99 (s, 6H), 1.42 (s, 9H), 0.43 (s, 6H); ^{13}C NMR (C_6D_6) δ 140.6, 137.9, 104.0, 62.1, 32.7, 16.1, 13.0, 5.4.

Preparation 2

In a drybox, 4.0 mL of 2.0 M isopropylmagnesium chloride in diethyl ether was syringed into a 100 mL flask. The ether was removed under reduced pressure to leave a colorless oil. 20 mL of a 4:1 (by volume) toluene:THF mixture was added followed by 0.97 g of (tert-butylamino)dimethyl-(tetramethylcyclopentadienyl)silane. The solution was heated to reflux. After 8-10 hours, a white precipitate began to form. After refluxing for a total of 27 hours, the solution was cooled and the volatile materials were removed under reduced pressure. The white solid residue was slurried in pentane and filtered to leave a white powder (1.23 g, 62 percent yield) of $Me_4C_5SiMe_2N$-t-$BuMg_2Cl_2(THF)_2$.

In the drybox, 0.50 g of $TiCl_3(THF)_3$ was suspended in 10 mL of THF. 0.69 g of solid $Me_4C_5SiMe_2N$-t-$BuMg_2Cl_2(THF)_2$ was added, resulting in a color change from pale blue to deep purple. After 15 minutes, 0.35 g of AgCl was added to the solution. The color immediately began to lighten to a pale green-yellow. After 1 1/2 hours, the THF was removed under reduced pressure to leave a yellow-green solid. Toluene (20 mL) was added, the solution was filtered, and the toluene was removed under pressure to leave a yellow-green microcrystalline solid, 0.51 g (quantitative yield). The product's identity was confirmed as (tert-butylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride by ^1H NMR, (C_6D_6): δ 1.992 (s), 1.986 (s), 1.414 (s), 0.414 (s).

Preparation 3

$TiCl_4$, 0.72 g (3.80 mmol) was added to 35 mL of frozen THF (-196° C) in a flask. The mixture was warmed to -78° C. A solution of 1.0 g (3.80 mmol) dilithium (tert-butylamido)dimethyl-(tetramethylcyclopentadienyl)silane in THF was slowly added. The resulting yellow solution was warmed to room temperature and stirred overnight. The solvent was removed to give a dark residue which was extracted with pentane and filtered. The product ($C_5Me_4(Me_2SiN$-t-Bu)$TiCl_2$) was obtained as a dark greenish-yellow crystalline material after being recrystallized twice from pentane at -35 to -40° C. Identification was confirmed by ^{13}C and ^1H NMR.

Preparation 4

In the drybox, $TiCl_3(THF)_3$ (2.0 g, 5.40 mmol) was suspended in 40 mL of THF. Dilithio (tert-butylamido)dimethyl(tetramethylcyclopentadienyl)silane (1.42 g, 5.39 mmol) was then added, resulting in an immediate darkening of the color, eventually to a deep blue. After 1 1/2 hours of stirring, AgCl (0.84 g, 5.86 mmol) was added. The color immediately began to lighten to a red/orange. After 1 1/2 hours of stirring, the THF was removed under reduced pressure. Diethyl ether (50 mL) was added, the solution was filtered, and the volatile materials were removed under reduced pressure. This yielded 1.91 g of the product (tert-butylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride. ^1H NMR (C_6D_6): δ 1.992 (s), 1.987 (s), 1.415 (s), 0.415 (s).

Polymerization

Polymerization of a styrene/ethylene mixture was accomplished by combining 1.65 mL of a 10 percent solution of MAO in toluene with a solution of 45 mL of toluene and 50 mL styrene in a stainless steel shot tank. 250 µL of a 0.010 M solution of (tert-butylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)-silanetitanium dichloride was added to 2.5 mL of toluene in a second shot tank. Both shot tanks were sealed, removed from the glove box, and attached to a 600 mL stainless steel pressure vessel. The pressure vessel was evacuated and purged with argon.

The styrene/toluene/MAO solution was added to the pressure vessel and warmed to 89° C under 620 kPa (90 psig) ethylene with stirring. At this time the catalyst solution was added and the pressure was increased to 1275 kPa (185 psig) and regulated between 1240-1275Kpa (180-185 psig). An exotherm raised the temperature to 95° C. The temperature was lowered to 90° C and was then regulated between 90-92° C for the remainder of the reaction.

After 1.0 h the ethylene feed was discontinued. The reaction was vented to the atmosphere and cooled to 30° C at which time methanol was added. The product was collected, washed with methanol and residual solvents were removed under reduced pressure at 120° C which resulted in 9.02 g of material. ^{13}C NMR analysis of this material showed it to be a random copolymer of styrene (15.2 percent on a molar basis) and ethylene, free of peaks attributed to polystyrene.

Example 3 (Olefin Polymerization)

Ethylene was polymerized by combining 5 mL of a 1 M solution of triethyl aluminum in mixed C_6 alkane solvent and 0.5 mL of a 0.01 M solution of (tert-butylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride in toluene in a stainless steel (SS) shot tank. The titanium catalyst and triethyl aluminum cocatalyst solution was then added under pressure to a 3 L SS pressure vessel containing 2 L of mixed alkane solvent (Isopar™ E, available from Exxon Chemicals, Inc.) under 3100 kPa (450 psig) ethylene at 150°C. The reaction temperature was maintained at 150°C for 10 minutes. The ethylene pressure was held constant, and a mass-flow meter measured the uptake of ethylene to be 15.7 g. The polymer solution was then removed from the pressure vessel and the polyethylene was recovered after drying under reduced pressure at 90°C overnight. Yield was 15.7 g.

Example 4 (Olefin Copolymer Polymerization)

In a glove box under argon atmosphere, 5.0 mL of 1.0 M solution of methylaluminoxane (MAO) in toluene was combined with 50 mL of 1-octene in a stainless steel (SS) shot tank fitted with ball valves on both ends. In another SS shot tank 500 µL (5.06 µmol) of a 0.0101 M solution of (tert-butylamido)dimethyl-(tetramethyl-η^5-cyclopentadienyl)silanezirconium dichloride in toluene was added to 2 mL toluene.

The shot tanks were sealed, removed from the glove box and attached to a 600 mL SS pressure vessel. The pressure vessel was evacuated and purged with argon. The solution of 1-octene and MAO was added to the pressure vessel. The solution was warmed to 89°C under 620 kPa (90 psig) ethylene with stirring. At this time the catalyst solution was added. An exothermic reaction occurred which raised the temperature to 142°C. The ethylene pressure was maintained between 1310-1345 kPa (190-195 psig).

After 0.5 hour the ethylene feed was discontinued. The reactor was cooled to 30°C, vented to the atmosphere, and the reaction was quenched with methanol. The product was collected on a fritted filter and washed with methanol. Residual solvents were removed under reduced pressure at 110°C which resulted in 35 g of material. ^{13}C NMR analysis indicated that 1-octene was incorporated into the polymer in an amount of 7.8 mole percent. Differential Scanning Calorimetry (DSC) indicated a Tm of 100°C. Density 0.895 g/mL, Mw = 44,000, Mw/Mn = 6.8

Example 5 (Olefin Copolymer Polymerization)

The procedure of Example 4 was substantially repeated excepting that 50 mL of 1-hexene was used instead of 1-octene. The temperature of the reaction was maintained at 133-140°C. Polymer yield was 37 g. Incorporation of 1-hexene was 8 percent on a molar basis, 21 percent by weight.

Example 6 (α-Olefin Homopolymerization)

A. 4-Methyl-1-pentene (6.0 mL, 4.0 g) was added to 1.0 mL of a 1.0 M MAO solution in toluene in a 20 mL crimp-top vial. To this was added 100 µL of a 0.01172 M toluene solution of the zirconium complex catalyst of Example 4. The vial was sealed, shaken, and allowed to stand at room temperature (ca. 20°C) for 16 hours, then heated to 48°C for an additional 24 hours. The viscous polymer solution was precipitated by the addition of methanol. The resulting polymer was collected and the volatile components removed under reduced pressure for four hours at 100°C to give 3.8 g of a clear polymer (95 percent yield). ^{13}C NMR analysis indicated that the polymer was atactic poly-4-methyl-1-pentene.

B. The procedure of Polymerization A was essentially repeated. 3.4 g of 1-hexene, 1.0 mL of MAO solution, and 100 µL of the catalyst solution were added to a 20 mL crimp-top vial in an argon-filled drybox. The vial was sealed and heated at 50°C overnight. After quenching with acidified ethanol and drying there was obtained 3.0 g of poly(1-hexene).

Example 7 (Ethylene Homopolym rization)

A SS shot tank was charged with 500 µL (5.0 µmol) of a 0.010 M toluene solution of (tert-butylamido)-dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride and 2.5 mL of toluene in an argon filled glov box. In a second SS shot tank, 5.0 mL of a 1.0 M solution of MAO in toluene was added to 92 mL of

toluene. Both shot tanks were sealed, removed from the glove box and attached to a 600 mL pressure vessel. The pressure vessel was evacuated and flushed with argon and then flushed with ethylene. The cocatalyst solution was added to the pressure vessel and heated to 89 °C under an ethylene pressure of 620 kPa (90 psig). The catalyst solution was added to the reactor at this time. The temperature rose to 109 °C within seconds as a result of an exothermic reaction. The ethylene pressure was regulated between 1240-1275 kPa (180-185 psig). After 0.5 hours the reactor temperature had increased to about 110 °C and the uptake of ethylene increased. After 1.0 hours ethylene feed was discontinued; the reactor was vented to the atmosphere, and allowed to cool. The pressure vessel was opened, quenched with methanol, and the polymer was isolated. After removing the volatile components, the yield of polyethylene was 24 g.

Example 8 Hindered Vinyl Aliphatic Monomer Polymerization

4-vinylcyclohexene was purified by vacuum distillation from Na/K alloy. The procedure of Example 4 was substantially repeated using, 50 mL of 4-vinylcyclohexene with 5.0 mL of a solution of 1.0 M methylaluminoxane (MAO) cocatalyst in toluene in one shot tank and 500 µL of a 0.010 M solution of (tert-butylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanezirconium dichloride in toluene added to 2 mL toluene in the other shot tank.

The exothermic reaction occurred which raised the temperature to 114 °C. The ethylene feed was discontinued after 1h and the cooled and vented reaction was quenched with acidified methanol.

The product was 12.6 g of material. ^{13}C NMR analysis indicated that vinylcyclohexene was incorporated into the polymer in an amount of 1.5 mole percent.

Example 9 (Ethylene/Styrene Copolymerization)

The above polymerization procedure was substantially followed except that the reaction temperature was 90 °C. The reactor was filled with 150 mL of mixed alkane solvent, 500 mL of styrene and 8 mL of 15 percent MAO in toluene (1000 Al:Ti). The reactor was saturated with 1240 kPa (180 psig) of ethylene, and 20 micromoles of $[(C_5Me_4)SiMe_2(N\text{-phenyl})]TiCl_2$ was added to begin the polymerization. Ethylene was provided on demand at 1240 kPa (180 psig). After 60 minutes, the solution was drained from the reactor into a container which had a small amount of antioxidant. The polymer was dried under vacuum. The polymer yield was 26.6 g, melt index (I_2) = 26.6. ^{13}C NMR NMR analysis indicated the polymer was 47 mole percent styrene (76 weight percent). No isotactic, atactic, or syndiotactic sequences were observed.

Example 10 Ethylene/Styrene Copolymerization

The reaction conditions of Example 9 were substantially repeated to prepare styrene/ethylene copolymers having differing styrene content. The catalyst was (tert-butylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride except where noted. MAO cocatalyst was employed in an amount to provide an Al:M atomic ratio of 1000:1. Reaction conditions are contained in Table I.

Table I

Run	mg (complex)	T (°C)	Solvent, amt. (mL)[b]	Ethylene Pressure kPa (psig)	Styrene (mL)	Time (h)	Yield (g)	mol % Styrene	Mw	Mw/Mn
1	0.92	90	T,50	1240 (180)	50	1.0	9	15.2	147,000	2.5
2	2.50	90	T,138	1240 (180)	138	2.0	29	18.4	65,100	2.7
3	2.20	90	T,160	1240 (180)	80	2.0	27	11.7	70,100	2.6
4	2.20	90	T,204	1240 (180)	36	2.0	30	8.1	72,300	2.5
5	3.70	90	I,350	1515 (220)	350	1.0	57	10.3	121,000	2.8
6	3.70	90	I,525	1515 (220)	175	0.75	70	6.8	304,000	2.6
7	3.70	90	I,600	1515 (220)	100	0.33	46	4.8	180,000	2.6
8	3.70	90	I,440	1515 (220)	260	0.33	43	9.0	172,000	2.5
9	1.90	90	I,650	1515 (220)	50	0.5	12	2.5	113,000	3.2
10	1.90	90	I,650	1515 (220)	50	0.5	40	2.8	154,000	2.6
11	2.20	90	T,180	1240 (180)	60	2.0	30	13.3	78,600	3.1
12[a]	2.30	90	T,180	1240 (180)	60	2.0	11	37.0	-	-

a. catalyst was (phenylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride
b. T = toluene, I = mixed alkanes

Examples 11-32

In these examples, a 4 liter autoclave was charged with 2000 mL of mixed alkane solvent (Isopar-E) followed by various amounts of 1-octene. The catalyst was (tert-butylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)-silanetitanium dichloride, dissolved in toluene. The cocatalyst was a 10 percent solution of MAO in toluene. Hydrogen, if desired, was added by expansion from a 100 mL vessel at a pressure indicated above the operating pressure of the reactor. The reactor was filled with solvent, 1-octene and MAO, heated to the reaction temperature, then pressurized to 3100 kPa (450 psig) with ethylene until the solution was satuated. The hydrogen (if any) was expanded into the reactor, followed by the addition of the catalyst solution. After 10 minutes, the solution was drained from the reactor into a container which had a small amount of antioxidant (Irganox 1010®, available from Ciba-Geigy). The polymer was dried under vacuum. Results are contained in Table II.

Table II

Ex.	Reactor Temp (°C)	Octene (mL)	ΔH_2 kPa[a](psig)	Catalyst mmoles	Al:Ti[b]	Polymer Yield (g)	Mw	Mn	Mw/Mn	Melt Point °C	Density g/mL	Melt Index[c]
11	140	300	0	0.02	500:1	182	-	-	-	91	0.9063	1.72
12	160	300	0	0.02	500:1	61	50,900	12,800	3.98	95[d]	0.9177	16.28
13	140	300	690 (100)	0.02	500:1	157	57,500	14,900	3.86	96	0.9175	7.91
14	160	300	690 (100)	0.02	500:1	58	38,500	10,700	3.60	100[d]	0.9230	31.69
15	140	150	345 (50)	0.02	500:1	128	66,500	17,400	3.82	105	0.9174	3.34
16	160	150	345 (50)	0.02	500:1	90	53,000	13,400	3.96	106[d]	0.9317	10.66
17	140	450	345 (50)	0.02	500:1	148	71,700	17,100	4.19	86	0.9010	3.84
18	160	450	345 (50)	0.02	500:1	55	42,500	11,400	3.73	90[d]	0.9045	31.20
19	150	150	0	0.02	500:1	75	71,700	16,500	4.35	108	0.9276	2.46
20	150	150	690 (100)	0.02	500:1	85	44,900	13,400	3.35	108	0.9261	18.42
21	150	450	0	0.02	500:1	107	62,500	14,800	4.22	92[d]	0.9090	5.34
22	150	450	690 (100)	0.02	500:1	85	58,200	12,900	4.51	124	0.9516	6.38
23	150	300	345 (50)	0.02	500:1	100	51,000	14,000	3.64	95[d]	0.9130	13.62
24	150	300	345 (50)	0.02	500:1	93	53,700	14,700	3.65	96[d]	0.9121	10.12
25	150	300	690 (100)	0.02	500:1	115	43,000	14,200	3.03	95[d]	0.9118	31.53
26	130	150	345 (50)	0.02	500:1	166	105,000	23,200	4.53	109	0.9198	0.18
27	130	150	345 (50)	0.02	250:1	147	136,000	29,400	4.63	110	0.9197	0.15
28	130	150	345 (50)	0.02	100:1	83	146,000	26,300	5.55	105	0.9153	0.15
29	110	150	345 (50)	0.01	250:1	98	161,000	42,000	3.83	106	0.9140	0.15
30	120	300	345 (50)	0.02	250:1	123	112,000	28,500	3.93	89	0.9016	0.45
31	110	450	345 (50)	0.02	250:1	145	130,000	37,400	3.48	76	≤0.9000	0.22
32	110	300	345 (50)	0.02	250:1	160	141,000	35,600	3.96	82	≤0.9000	0.15

a. hydrogen partial pressure
b. equivalent ratio assuming 58 MW for MAO
c. I_2, ASTM D-1238 Procedure A, condition E.

Examples 33-42

The procedure of Examples 11-32 was substantially repeated, except that the catalyst was (tert-butylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanezirconium dichloride. Results are contained in Table III.

Table III

Example	Temp C	mL Octene	ΔH_2 kPa (psig)	Zr (mmole)	Al:Zr[a]	Zr eff x 10^{-3}[b]
33	150	300	345 (50)	0.02	500	50
34	140	300	345 (50)	0.01	500	122
35	130	300	345 (50)	0.005	500	285
36	130	450	345 (50)	0.005	500	302
37	130	150	345 (50)	0.005	500	230
38	130	150	345 (50)	0.01	250	158
39	130	150	345 (50)	0.02	100	104
40	130	300	345 (50)	0.01	100	154
41	140	450	0	0.015	200	84
42	140	450	690 (100)	0.02	200	101

a. equivalent ratio, assuming 58 Mw for MAO
b. catalyst efficiency, g polymer.1 g metal

Examples 43 - 57

The procedure of Examples 11-32 was substantially followed except that a 2000 mL reactor was used. The catalyst was (tert-butylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride (2 mL of a 0.005 M solution in toluene, 10 µmoles). The cocatalyst was 15 percent MAO in toluene (2 mL, 500 Al:Ti). Results are contained in Table IV.

Table IV

Example	Temp. C	Δ H_2 kPa[a] (psig)	1-Octene mole	g Polymer	Melt Index [b]	Density
43	100	170 (25)	1.59	70.0	<.1	0.8700
44	80	170 (25)	1.59	67.0	<.1	0.8672
45	90	170 (25)	1.85	98.2		0.8582
46	100	170 (25)	2.12	118.3	0.96	0.8575
47	100	345 (50)	1.85	131.9	7.48	0.8552
48	80	170 (25)	2.12	139.3	0.93	0.8528
49	90	0	1.59	104.4	0.25	0.8594
50	90	345 (50)	2.12	133.1		0.8556
51	90	170 (25)	1.85	130.2		0.8550
52	100	0	1.85	110.0	0.66	0.8570
53	90	170 (25)	1.85	141.0		0.8545
54	80	345 (50)	1.85	161.2	5.44	0.8525
55	80	0	1.85	118.1	0.48	0.8536
56	90	0	2.12	150.8	3.12	0.8516
57	90	345 (50)	1.59	136.7	3.43	0.8578

a. hydrogen partial pressure
b. I_2, ASTM D-1238 Procedure A, condition E.

Examples 58-77 Olefin polymerization

Ethylene and/or ethylene/1-octene were respectively polymerized as a homopolymer or copolymer by adding a solution of the appropriate catalyst in combination with MAO or triethyl aluminum cocatalyst to a 3L SS pressure vessel containing mixed C_6 alkane solvent/1-octene (with varying ratios) under 3100 kPa (450 psig) of ethylene at 150 °C (or 175 °C where indicated) for 10 minutes. The ethylene pressure was held constant and a mass flow meter measured the uptake of ethylene. The consequent polymer was then removed from the pressure vessel and dried under reduced pressure at 90 °C overnight. Results are contained in Table V.

Table V

Example	Catalyst [a,b]	Solvent/Octene [c]	Wt. of polymer (g)	Melt Index (I_2)	Mw	Mn	Mw/Mn
58	Ti	1/1	61.1	79.0	45,600	9100	5.01
59	Ti	2/0.3	48.7	1.7	88,300	10100	8.74
60	Ti	1/1	41.5	137.6	36,300	9950	3.68
61	Zr	1/1	55.2	1324.9	--	--	--
62	Zr	2/0.15	33.3	10.3	--	--	--
63	Zr	2/0	25.8	8.8	58,400	5310	10.90
64	Zr	0/2	102.9	168.1	30,900	8150	3.79
65[d]	Zr	2.0	17.8	147.1	--	--	--
66	Zr	2/0	25.3	240.8	--	--	--
67	Ti	2/0	15.6	4.4	--	--	--
68	Zr	2/0	20.6	2.8	101,000	7700	13.10
69	Zr	2/0.3	44.0	17.1	47,300	6550	7.22
70	Zr	0/2	96.6	149.2	43,500	4710	5.87
71	Ti	1/1	47.5	25.8	54,000	10800	5.00
72	Ti	2/0.3	74.5	56.3	44,400	12100	3.67
73	Ti	2/0.3	75.0	56.9	44,700	9800	4.56
74	Ti	2/0	15.6	--	--	--	--
75[e]	Ti	2/0.15	19.9	--	--	--	--
76	Ti	2/0.15	34.5	1.0	--	--	--
77	Zr	0/2	88.3	111.7	35,100	6440	5.45

a) Ti = (tert-butylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitantium dichloride
Zr = (tert-butylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanezirconium dichloride
b) Metal.Al ratio = 1.1000 assuming 58 MW for MAO
c) liters of each
d) Run at 175 °C
e) Used triethylaluminum as cocatalyst; metal.Al was 1:1000

Example 78 Preparation of Supported (tert-butylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)-silanetitanium dichloride

0.100g of dehydroxylated silica (-OH concentration = 1 mmol/g SiO_2) was slurried in 20 mL of mixed C_6 alkane solvent under a nitrogen atmosphere in a dri-box, with stirring in a 50 mL Erlenmeyer flask. From this slurry 1.0 mL was removed by syringe and combined with 1.10 mL of a 0.011 M toluene solution of (tert-butylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride in a 5 mL rounded-bottomed flask and stirred for 12 h. After this period 6.7 mL of a 10 percent (w/w) solution of methyl aluminoxane (MAO) in toluene was added to the silica containing solution.

Polymerization

The polymerization was conducted by adding under pressure the above titanium/silica/MAO slurry in a 3 L SS pressure vessel containing 2 L of mixed alkane solvent under 3100 kPa (450 psig) of ethylene at 150 °C for 10 minutes. The ethylene pressure was held constant and a mass flow meter measured the uptake of ethylene to be 26.7 g. The polymer solution was then removed from the pressure vessel and the polyethylene was recovered after drying under reduced pressure at 90 °C overnight. Yield was 30.0 g.

Example 79 Preparation of (2-Methoxyphenylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride

(a) ((Tetramethylcyclopentadienyl)dimethylsilyl) (2-methoxyphenyl)amine

To 1.3 g (5.9 mmol) ((tetramethylcyclopentadienyl)dimethylsilyl)chloride in 50 mL tetrahydrofuran (THF) was added 0.86 g (5.9 mmol) sodium 2-methoxyanilide. The mixture was stirred overnight. The solvent was removed under reduced pressure and the residue extracted with pentane. The pentane extracts were filtered, combined, and concentrated to give a pale yellow liquid. Yield 1.4 g (79%). ^{1}H NMR (benzene-d_6) δ 6.91 (m, 2.2), 6.74 (m, 1.1), 6.57 (d, 1.1, J = 9), 4.25 (s, 1), 3.32 (s, 3.7), 1.93 (s,6.7), 1.80 (s, 6.8), 0.13 (s, 6.3).

(b) Dilithium ((tetramethylcyclopentadienyl)dimethylsilyl)-(2-methoxyphenyl)amide.

To 1.4 g (4.6 mmol) ((tetramethylcyclopentadienyl)dimethylsilyl)(2-methoxyphenyl)amine in diethyl ether was added dropwise 3.9 mL of 2.5 M butyl lithium (9.8 mmol) in hexane solvent. A white precipitate formed. Pentane was added to the mixture. The slurry was filtered and the solids washed with pentane.

(c) (2-Methoxyphenylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride

To 1.6 g of dilithium ((tetramethylcyclopentadienyl)dimethylsilyl)(2-methoxyphenyl)amide slurried in toluene was added 0.85 g $TiCl_4$. The mixture was stirred for three days, filtered, and the solvent was removed under reduced pressure. The residue was slurried in pentane and filtered to give a dark powder. Yield 0.77 g (41%). ^{1}H NMR (benzene-d_6) δ 4.10 (s, 3), 2.20 (s, 6.4), 1.99 (s, 6.6), 0.40 (s, 6.3).

Example 80 Preparation of (4-Fluorophenylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride

(a) ((Tetramethylcyclopentadienyl)dimethylsilyl)(4-fluorophenyl)amine

Equimolar quantities of ((tetramethylcyclopentadienyl)dimethylsilyl)chloride and lithium 4-fluorophenyl anilide were combined in THF and the mixture stirred overnight. The solvent was removed under reduced pressure. ^{1}H NMR (benzene-d_6) δ 6.79 (m, 2.5), 6.33 (m, 2.4), 2.95 (s,1), 2.90 (s, 1), 1.87 (s, 6.9), 1.79 (s, 6.9), 0.02 (s, 5.8).

(b) Dilithium ((tetramethylcyclopentadienyl)dimethylsilyl)(4-fluorophenyl)amide

((Tetramethylcyclopentadienyl)dimethylsilyl)(4-fluorophenyl)amine in diethyl ether solvent and butyl lithium 2.5 M in hexane solvent were combined in equivalent amounts. A white precipitate formed. Pentane was added to the slurry. The precipitate was filtered, washed with pentane and dried. ^{1}H NMR (THF-d_8) δ 7.28 (m, 2.0), 6.77 (m, 2), 3.27 (s, 2.7), 2.05 (s, 5.2), 2.01(s, 5.2), 0.44 (s, 4.6)

(c) (4-Fluorophenylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silane titanium dichloride

To 0.59 g (1.6 mmol) $TiCl_3$•3THF in 50 mL THF was added 0.50 g (1.7 mmol) dilithium (-(tetramethylcyclopentadienyl)dimethylsilyl)(4-fluorophenyl)amide. After 0.5 h, 0.25 g (1.8 mmol) AgCl was added. After 2 h the solvent was removed under reduced pressure. The residue was extracted with diethyl ether. The ether extracts were filtered, combined, and concentrated under reduced pressure to give a red glassy solid. Dissolution into toluene and reconcentration produced a waxy solid. This solid was extracted into pentane. The pentane extracts were filtered, combined, and concentrated to produce a waxy solid. This was slurried with a small amount of pentane (2 mL) and filtered to give a red powder. The yield was 0.18 g (28%). ^{1}H NMR (benzene-d_6) δ 7.10 (t), 6.80 (t), 2.00 (s), 1.97 (s), 0.35 (s).

Polymerization

The polymerization procedure of Examples 11-32 was substantially followed using 1000 mL of mixed alkane solvent, 200 mL of 1-octene and 5 mL of 15 percent MAO in toluene (1280 Al:Ti) and a reaction temperature of 130 °C. Hydrogen was supplied from a 75 mL tank pressurized to 3450 kPa (500 psig) to give a delta pressure of 345 kPa (50 psi). 10 Micromoles of the above complex was added to begin the polymerization. Ethylene was provided on demand at 3100 kPa (450 psig). The polymer yield was 12.8 g, Mw = 103,000, Mw/Mn = 4.77, density = 0.9387, melt index = 6.37.

Example 81 Preparation of ((2,6-Di(1-methylethyl)phenyl)amido)dimethyl(tetramethyl-η^5-cyclopentadienyl)-amidotitanium dichloride

Dilithium ((tetramethylcyclopentadienyl)dimethylsilyl)(2,6-di(1-methylethyl)phenyl)amide was prepared in a manner analogous to Example 80.

To 1.5 g (4 mmol) $TiCl_3 \cdot 3THF$ in 25 mL THF was added 1.5 g (4 mmol) dilithium (-(tetramethylcyclopentadienyl)dimethylsilyl)(2,6-di(1-methylethyl)phenyl)amide. After 0.5 h 0.63 g (4 mmol) AgCl was added. After 1.5 h the solvent was removed under reduced pressure. The residue was extracted with pentane (3 x 8 mL). The pentane insoluble residue was extracted with diethyl ether. The ether extract was filtered and evaporated to dryness to give a yellow crystalline solid. ^1H NMR (benzene-d6) d 3.04 (heptet, 2, J = 6.7), 2.18 (s, 5.8), 1.98 (s, 5.8), 1.49 (d, 5.8, J = 6.5), 1.12 (d, 6.2, J = 6.8), 0.48 (s, 5.2).

Polymerization

The polymerization procedure of Example was followed using 10 micromoles of the above complex. The polymer yield was 14.7 g.

Example 82 Preparation of (4-Methoxyphenylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride

To 0.73 g $TiCl_4 \cdot 2THF$ in 30 mL toluene was added 0.7 g of dilithium ((tetramethylcyclopentadienyl)-dimethylsilyl)(4-methoxyphenyl)amide (prepared in a method analogous to Example 81. The mixture was stirred for two days, filtered, and concentrated under reduced pressure. The residue was slurried in pentane and filtered to give a brick red powder. Yield 0.61 g (67%). ^1H NMR (benzene-d_6) δ 7.28 (d, 2, J = 8.8), 6.78 (d, 2, J = 8.9), 3.27 (s, 2.8), 2.05 (s, 5.6), 2.01 (s, 5.6), 0.44 (s, 4.8).

Polymerization

The polymerization procedure of Example 80 was followed using 10 micromoles of the above complex. The polymer yield was 7.2 g, Mw = 79,800, Mw/Mn = 21.5, melt index = 2.90.

Example 83 Preparation of (tetramethyl-η^5-cyclopentadienyl)dimethyl(1-methylethoxy)silanetitanium trichloride

(a) (Tetramethylcyclopentadienyl)dimethyl(1-methylethoxy)silane

To 1.0 g (4.8 mmol) (tetramethylcyclopentadiene)dimethylsilyl chloride in 10 mL toluene was added 0.38 mL (5.0 mmol) 2-propanol followed by 0.66 mL (4.7 mmol) triethylamine. The mixture was filtered and the solids washed with mixed C_6 alkane solvent. The wash and the filtrate were combined and concentrated und r reduced pressure to give a pal yellow liquid. ^1H NMR (b nzen -d_6) δ 3.85 (h ptet, 1, J = 6.0), 2.9 (s, 1.1), 2.03 (s, 5.7), 1.8 (s, 6.3), 1.10 (d, 6.3, J = 6.0), -0.02 (s, 5.0).

(b) Potassium (dimethyl(1-methylethoxy)silyl)tetramethyl-cyclopentadienide)

To 0.51 g (2.1 mmol) (tetramethylcyclopentadienyl)dimethyl(1-methylethoxy)silane in toluene was added 0.33 g (2.5 mmol) potassium benzide. The solution was filtered after 3 days and the solvent was removed under reduced pressure to give an oil. The oil was washed with pentane. Residual pentane was removed under reduced pressure to give an orange glassy solid. ^1H NMR (THF-d_8) δ 3.89 (heptet, 1, J = 6.1), 2.00 (s,6.1), 1.87 (s, 5.7), 1.05 (d, 5.1, J = 6.1), 0.22 (s, 4.4).

(c) (Tetramethyl-η^5-cyclopentadienyl)dimethyl(1-methylethoxy)silanetitanium trichloride

To 0.42 g (1.1 mmol) $TiCl_3$•3THF in 50 mL THF was added dropwise 0.83 mmol potassium (dimethyl-(1-methylethoxy)silyl)tetramethylcyclopentadienide) in 15 mL THF. One hour after addition was complete 0.2 g (1.3 mmol) AgCl was added. The resulting mixture was stirred for 18 h. The solvent was removed under reduced pressure and the residue extracted with pentane. The pentane extracts were filtered, combined, and evaporated to a red oil. The red oil was slurried in pentane and the mixture was filtered. The filtrate was stored art -30° c for 3 weeks which resulted in the precipitation of an orange solid. The solution was decanted from the solid. ^1H NMR (benzene-d_6) δ 3.8(heptet, 1, J = 6.0), 2.35 (s, 6.9), 1.86 (s, 7.4), 1.04 (d, 7.1, J = 6.0), 0.45(s, 6.7) .00(s), 1.97 (s), 0.35 (s).

Example 84 Preparation of 1-(Tert-butylamido)-2-(tetramethyl-η^5-cyclopentadienyl)-1,1,2,2-tetramethyl-disilanetitanium dichloride

(a) 1-Chloro-2-(tetramethylcyclopentadienyl)-1,1,2,2-tetramethyldisilane

To a solution of 4.802 g (25.7 mmol) 1,2-dichloro-1,1,2,2-tetramethyldisilane in 50 mL dimethylether was slowly added a solution of 2.285 g (12.8 mmol) sodium 1,2,3,4-tetramethylcyclopentadienide in 30 mL dimethylether. The reaction mixture was stirred several hours, then the solvent was removed, the residue was extracted with pentane and filtered. The pentane was removed under reduced pressure to give the product as a light-yellow oil. Mass spec: m/e 272 (8%). ^1H NMR (C_6D_6) δ 2.70 (s, 1H), 1.83 (s, 6H), 1.69 (s, 6H), 0.28 (s, 6H), 0.23 (s, 6H); ^{13}C NMR (C_6D_6) δ 135.8, 134.0, 54.4, 14.6, 11.4, 3.2, -2.4.

(b) 1-(Tert-butylamino)-2-(tetramethylcyclopentadienyl)-1,1,2,2-tetramethyldisilane

To a solution of 3.000 g (11.0 mmol) 1-chloro-2-(tetramethylcyclopentadienyl)-1,1,2,2-tetramethyldisilane in 50 mL ether was added 2.422 g (33.1 mmol) tert-butylamine. Precipitate formed rapidly. The slurry was stirred for several days at room temperature, then was gently heated to drive the reaction to completion. The solvent was removed, the residue was extracted with pentane, the amine hydrochloride was filtered and the pentane was removed under reduced pressure to give the product as a yellow oil. The yield was 3.150 (92.5%). Mass spec: m/e 309. ^1H NMR (C_6D_6) δ 2.75 (s, 1H), 1.95 (s, 6H), 1.82 (s, 6H),1.08 (s, 9H), 0.51 (s, 1H), 0.24 (s, 6H), 0.16 (s, 6H); ^{13}C NMR (C_6D_6) δ 135.2, 134.4, 55.2, 50.3, 34.1, 14.9 11.6, 3.3, -1.4.

(c) Dilithium 1-(tert-butylamido)-2-(tetramethylcyclopenta-dienyl)-1,1,2,2-tetramethyldisilane

To a solution of 3.00 g (9.72 mmol) 1-(tert-butylamino)-2-(tetramethylcyclopentadienyl)-1,1,2,2-tetramethyldisilane in 100 mL ether was slowly added 7.70 mL of 2.60 M (20.2 mmol) butyl lithium in mixed C_6 alkane solvent. The resulting slurry was stirred several hours, then filtered and washed with ether, then dried under reduced pressure to give the product as a white powder. The yield was 2.918 g (93.4%). ^1H NMR (THF d-8) δ 2.05 (s, 6H), 1.91 (s, 6H),0.87 (s, 9H), 0.25 (s, 6H), -0.03 (s, 6H); ^{13}C NMR (THF d-8) δ 117.3, 113.6, 53.5, 38.4, 34.1, 14.2 11.3, 8.4, 2.2.

(d) 1-(tert-butylamido)-2-(tetramethyl-η^5-cyclopentadienyl)-1,1,2,2-tetramethyldisilanetitanium dichlorid

A slurry of 0.7500 g (2.333 mmol)dilithium 1-(tert-butylamido)-2-(tetramethylcyclopentadienyl)-1,1,2,2-tetramethyldisilane and 0.7790 g (2.333 mmol) $TiCl_4(THF)_2$ in 50 mL toluene was stirred for several days.

The red-orange reaction mixture was filtered and the solvent was removed to give a sticky red solid. This was extracted with pentane and filtered. After concentration and cooling at -35 °C in a freezer, the shiny microcrystalline red product was collected on a frit and washed with cold pentane to remove a dark red oily material. Yield: 0.3643 g, 36.6%. ^1H NMR (C_6D_6) δ 2.20 (s, 6H), 1.94 (s, 6H), 1.48 (s 9H), 0.44 (s, 6H), 0.43 (s, 6H). ^{13}C NMR(C_6D_6) δ 137.7, 135.5, 112.7, 65.9, 35.4, 16.6, 12.5, 2.8, -2.1.

Polymerization

The polymerization procedure of Example 80 was followed using 10 micromoles of the above complex. The polymer yield was 12.1 g, Mw = 62,400, Mw/Mn = 8.45, melt index = 6.14, density = 0.9441.

Example 85 Preparation of 1-(Tert-butylamido)-2-(tetramethyl-η^5-cyclopentadienyl)-1,1,2,2-tetramethyl-disilanezirconium dichloride

A slurry of 0.7500 g (2.333 mmol) dilithium 1-(tertbutylamido)-2-(tetramethylcyclopentadienyl)-1,1,2,2-tetramethyl-disilane (prepared according to the technique of Example 84) and 0.5436 g (2.333 mmol) $ZrCl_4$ in 75 mL toluene was stirred for several days. The pale yellow reaction mixture was filtered and the solvent was removed. The residue was extracted with pentane and filtered. After concentration and cooling at -35 °C in a freezer, the product as colorless crystals was collected on a frit. Yield: 0.6720 g, 61.3%. ^1H NMR (C_6D_6) δ 2.14 (s, 6H), 1.94 (s, 6H), 1.49 (s, 9H), 0.36 (s, 6H), 0.34 (s, 6H). ^{13}C NMR (C_6D_6) δ 134.1, 131.0, 119.1, 58.4, 34.2, 15.1, 11.8, 4.7, -2.1.

Example 86 Preparation of (Tert-butylamido)(dimethyl)(tetramethyl-η^5-cyclopentadienyl)silanezirconium dimethyl

A solution of 0.5000 g (1.215 mmol) (tert-butylamido)(dimethyl)(tetramethylcyclopentadienyl)-silanezirconium dichloride in 35 mL ether was cooled to -40 °C. To this was slowly added 1.41 mL methyl lithium solution (1.72 M, 2.43 mmol). The reaction mixture was allowed to stir at room temperature for several hours. The solvent was removed and the residue was extracted with pentane and filtered. The filtrate was concentrated and chilled to -40 °C. The colorless crystals which formed were isolated by decanting away the supernatant. Yield: 0.2215 g, 49.2 percent ^1H NMR (C_6D_6) δ 1.97 (s, 6H), 1.91 (s, 6H), 1.40 (s, 9H), 0.46 (s, 6H), 0.00 (s, 6H). ^{13}C NMR (C_6D_6) δ 130.2, 125.3, 95.7, 54.7, 35.4, 34.0, 13.9, 10.9, 6.2.

Example 87 Preparation of Preparation of (tert-butylamido)dimethyl(η^5-cyclopentadienyl)silanetitanium dichloride

(a) (Chloro)(cyclopentadienyl)(dimethyl)silane

A solution of 149 g (1.16 mol) Me_2SiCl_2 in 750 mL diethyl ether was cooled to -78 °C. Solid sodium cyclopentadienide (30 g, 0.341 mol) was added via a powder addition funnel over a period of 1.5 hours. The reaction mixture was allowed to warm to room temperature and was stirred for 16 hours. The ether and some Me_2SiCl_2 were distilled out, then exhaustive vacuum distillation removed the remaining ether, Me_2SiCl_2 and the product from the NaCl formed in the reaction. The product after fractionation was obtained in good yield as a light-yellow oil. Mass spec: m/e 158 (16%).

(b) (Tert-butylamino)(cyclopentadienyl)(dimethyl)silane

To a solution of 3.69 g (50.4 mmol) tert-butyl amine in 45 mL THF was added 2.00 g (12.6 mmol) (chloro)(cyclopentadienyl)(dimethyl)silane. Precipitate formed quickly. The slurry was stirred for several days, then the amine hydrochloride was filtered off and the solvent was removed under reduced pressure to giv the product as a very pale yellowish oil. The yield was 2.069 g (84.2%). Mass spec: m/ 195 (6%). ^1H and ^{13}C NMR show the presence of several cyclopentadiene isomers.

(c) Dilithium (tert-butylamido)(cyclopentadienyl)(dimethyl)silane

To a solution of 1.500 g (7.69 mmol) (tertbutylamido)(cyclopentadienyl)(dimethyl)silane in 60 mL ether was slowly added 6.21 mL of a 1.72 M (10.68 mmol) ether solution of methyllithium, then 1.81 mL of 2.6 M (4.706 mmol) butyllithium in mixed alkane solvent (15.39 mmol total alkyllithiums). The resulting slurry was stirred overnight, then filtered and washed with pentane, then dried under reduced pressure to give the product as a white powder. The yield was 1.359 g (85.2%). ^1H NMR (THF d-8) δ 5.96 (t, 2H), 5.87 (t, 2H), 1.10 (s, 9H), 0.05 (s, 6H). ^{13}C NMR (THF d-8) d 114, 105.2, 103.5, 52, 38.3, 7.3.

(d) (Tert-butylamido)dimethyl(η^5-cyclopentadienyl)silane titanium dichloride

0.7000 g (3.38 mmol) Dilithium (tertbutylamido)(cyclopentadienyl)(dimethyl)silane and 1.128 g (3.38 mmol) $TiCl_4 \cdot (THF)_2$ were combined in a flask with 75 mL toluene. The resulting yellow slurry turned muddy red-brown within a few hours. The reaction mixture was stirred for several days then the red solution was filtered and the solvents removed under reduced pressure. The crystalline material formed was slurried with pentane and filtered to remove the soluble red impurity from the brown product. The yield was 0.5369 g (50.9%). ^1H NMR (C_6D_6) δ 6.60 (t, 2H), 6.07 (t, 2H), 1.38 (s, 9H), 0.18 (s, 6H). ^{13}C NMR (C_6D_6) δ 126.3, 125.6, 110.0,63.7, 32.2, -0.2.

Polymerization

The polymerization procedure of Example was followed using 10 micromoles of the above complex. The polymer yield was 28.1 g, Mw = 108,000, Mw/Mn = 3.22, density = 0.9073, melt index = 2.92.

Example 88 Preparation of (Tert-butylamido)dimethyl(η^5-cyclopentadienyl)silanezirconium dichloride

To 0.6747 g (2.90 mmol) $ZrCl_4$ in a flask was slowly added 4 mL diethyl ether, then 4 mL THF. The excess solvents were removed under vacuum to yield a solid which was broken up to a powder. The solid was combined with 0.6008 g (2.90 mmol) dilithium (tert-butylamido)(cyclopentadienyl)(dimethyl)silane (prepared according to the technique of Example 87 and 75 mL toluene. The resulting slurry was stirred for several days after which the colorless solution was filtered, the solvent removed under reduced pressure and the residue was slurried in pentane. The product was collected on a frit and dried under reduced pressure. Yield was 0.6186 g (60.0%). ^1H NMR (C_6D_6) δ 6.43 (t, 2H), 6.08 (t, 2H), 4.17 (br s, 6H), 1.27 (s, 9H), 1.03 (br s, 6H), 0.22 (s, 6H). ^{13}C NMR (C_6D_6) δ 122.0, 121.4, 109.5, 78, 57.2, 32.8, 25.2, 0.7. The structure was shown by x-ray crystallography to be dimeric (bridging chlorides) in the solid state.

Example 89 Preparation of (Anilido)(dimethyl)(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride

(a) (Anilido)(dimethy)(tetramethylcyclopentadienyl)silane

To a solution of 1.500 g (6.98 mmol) (chloro)(dimethyl)(tetramethylcyclopentadienyl)silane in 50 mL THF was slowly added 0.6911 g (6.98 mmol) lithium anilide. Monitoring by GC indicated the reaction was incomplete. Additional lithium anilide (0.08 g, 7.78 mmol total) was added. The reaction mixture was stirred overnight. The solvent was removed, the residue was extracted with pentane and filtered. The pentane was removed under reduced pressure to give the product as a pale yellow oil. The yield was 1.875 g (99.2%). Mass spec. m/e 271 (13%). ^1H NMR (C_6D_5) δ 7.14 (m, 2H), 6.76 (t, 1H), 6.60 (d, 2H), 3.08 (s, 1H), 3.04 (s, 1H), 1.89 (s, 6H), 1.79 (s, 6H), 0.07 (s, 6H). ^{13}C NMR (C_6D_5) δ 147.5, 136.3, 132.6, 129.6, 118.2, 116.9, 55.0, 14.3, 11.3, -2.2.

(b) Dilithium (anilido)(dimethyl)(tetramethylcyclopentadienyl)silane

To a solution of 1.875 g (6.91 mmol) (anilido)(dimethyl)(tetramethylcyclopentadienyl)silane in 50 mL

ether was slowly added 5.31 mL of 2.60 M (13.8 mmol) butyllithium in hexane solvent. A small amount of precipitate formed, but then dissolved. The reaction mixture was stirred overnight. The product appeared to have collected as a thick viscous oil in the ether solution The solvent was removed under reduced pressure. The resulting white solid was slurried in pentane, collected on a frit, washed with pentane and dried under reduced pressure to give the product as a white powder. The yield was 1.943 g (99.3%).

(c) (Anilido)(dimethyl)(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride

A slurry of 0.8025 g (2.333 mmol) dilithium (anilido)(dimethyl)(tetramethylcyclopentadienyl)silane and 0.9871 g (2.333 mmol) $TiCl_4(THF)_2$ in 70 mL toluene was stirred for several days. The red-brown reaction mixture was filtered and the solvent was removed. The solid was triturated in pentane and the product was collected on a frit and washed with cold pentane to remove a dark red oily material to give the product as a yellow-beige powder. Yield: 0.6400 g, 55.8%. ^1H NMR (C_6D_6) δ 7.32 (d, 2H), 7.18 (m, 2H), 6.85 (t, 1H), 2.02 (s, 6H), 1.99 (s, 6H), 0.42 (s, 6H). ^{13}C NMR (C_6D_6) δ 152.4, 141.9, 137.8, 129.3, 124.4, 119.6, 105.3, 16.1, 13.0, 2.7.

Polymerization 1

The polymerization procedure of Example 80 was followed using 10 micromoles of the above complex. The polymer yield was 12.8 g, Mw = 103,000, Mw/Mn = 4.77, density = 0.9387, melt index - 6.37.

Polymerization 2 Ethylene/Styrene Copolymerization

The above polymerization procedure was substantially followed except that 900 mL of mixed alkane solvent, 184 mL of styrene, 345 kPa (50 psi) delta hydrogen, and 20 micromoles of $[(C_5Me_4)SiMe_2(tert\text{-}butyl)]TiCl_2$ were used. The temperature of the reactor was 120 °C. After 10 minutes, the contents were removed from the reactor, and 62.3 g of polymer was recovered. The melt index was 3.68.

Example 90 Preparation of (Anilido)(dimethyl)(tetramethyl-η^5-cyclopentadienyl)silanezirconium dichloride

To 0.6905 g (2.963 mmol) $ZrCl_4$ in a flask was slowly added 3 mL diethyl ether, then 4 mL TNF. The excess solvents were removed under vacuum to yield a solid which was broken up to a powder. The solid was combined with 0.8044 g (2.963 mmol) dilithium (anilido)(dimethyl)(tetramethyl-η^5-cyclopentadienyl)-silane and 70 mL toluene. Within minutes the slurry color became pale yellow-green. The slurry was stirred for several days after which time the solution was filtered, the solvent removed under reduced pressure and the residue was slurried in pentane. The very pale yellowish product was collected on a frit and dried under reduced pressure. ^1H NMR (C_6D_6) δ 7.21 (t, 2H), 7.1 (t, 1H), 6.97 (m, 2H), 2.50 (s, 3H), 2.46 (s, 3H), 1.87 (s, 3H), 1.85 (s, 3H), 0.53 (s, 3H), 0.40 (s, 3H).

Example 91 Preparation of (a) (p-Toluidino)(dimethyl)(tetramethyl-η^5-cyclopentadienyl)silanezirconium dichloride

(p-Toluidino)(dimethyl)(tetramethylcyclopentadienyl) silane

To a solution of 2.000 g (9.302 mmol) (chloro)(dimethyl)(2,3,4,5-tetramethylcyclopentadienyl)silane in 70 mL THF was slowly added 1.259 g (9.302 mmol) lithium p-toluidide (0.3 ether adduct by ^1H NMR). The reaction mixture was stirred overnight. Monitoring by GC indicated the reaction was incompl te. Additional lithium p-toluidide was added in small lots (0.725 g, 14.7 mmol total). The solvent was removed, the residue was extracted with pentane and filtered. The pentane was removed und r reduced pressure to give the product as a yellow oil. The yield was 2.456 g (92.5%). Mass spec. m/e 285 (22%). ^1H NMR (C_6D_6) δ 6.96 (d, 2H), 6.57 (d, 2H), 3.07 (s, 1H), 3.01 (s, 1H), 2.17 (s, 3H), 1.91 (s, 6H), 1.80 (s, 6H), 0.08 (s, 6H). ^{13}C NMR (C_6D_6) δ 145.0, 136.2, 132.7, 130.2, 126.9, 116.9, 55.2, 20.5, 14.3, 11.3, -2.2.

(b) Dilithium (p-toluidino)(dimethyl)(tetramethylcyclopenta-dienyl)silane

To a solution of 2.233 g (7.82 mmol) (p-toluidino)(dimethyl)(tetramethylcyclopentadienyl)silane in 65 mL ether was slowly added 6.17 mL of 2.60 M (16.0 mmol) butyllithium in mixed C_6 alkane solvent. The precipitate-free reaction mixture was stirred overnight. The solvent was removed under reduced pressure. The resulting white solid was slurried in pentane, collected on a frit, washed with pentane and dried under reduced pressure to give the product as a white powder. The yeild was 2.34 g (100%). ^{1}H NMR (THF δ-8) d 6.42 (d, 2H), 6.18 (d, 2H), 2.09 (s, 6H), 2.01 (s, 3H), 1.94 (s, 6H), 0.36 (s, 6H). ^{13}C NMR (THF δ-8) δ 160.8, 129.1, 121.3, 115.9, 115.2, 112.2, 106.2, 20.8, 14.7, 11.7, 5.2.

(c) (p-Toluidino)(dimethyl)(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride

A slurry of 1.000 g (3.363 mmol) dilithium (p-toluidino)(dimethyl)(tetramethyl-η^5-cyclopentadienyl)silane and 1.123 g (3.363 mmol) $TiCl_4(THF)_2$ in 70 mL toluene. The reaction mixture was stirred several days, then filtered and the solvent was removed. The resulting solid was slurried in pentane and the product was collected on a frit and dried under reduced pressure. The yield of olive-brown powder was 0.7172 g, 53.0%. ^{1}H NMR (C_6D_6) δ 7.26 (d, 2H), 7.01 (d, 2H), 2.08 (s, 3H), 2.04 (s, 6H), 2.00 (s, 6H), 0.45 (s, 6H). ^{13}C NMR (C_6D_6) δ 150.3, 141.7, 137.5, 133.9, 130.0, 129.7, 119.6, 21.0, 20.6, 16.4, 16.0, 13.3, 12.8, 2.8, 2.6.

(d) (p-Toluidino)(dimethyl)(tetramethyl-η^5-cyclopentadienyl)silanezirconium dichloride

To 0.7836 g (3.363 mmol) $ZrCl_4$ in a flask was slowly added 3 mL diethyl ether, then 4 mL THF. The excess solvents were removed under vacuum to yield a solid which was broken up to a powder. The solid was combined with 1.000 g (3.363 mmol) dilithium (p-toluidino)(dimethyl)(tetramethyl-η^5-cyclopentadienyl)-silane and 70 mL toluene. The slurry was stirred for several days. The initially yellowish slurry turned brownish. The yellow solution was filtered, the solvent removed under reduced pressure and the solid was slurried in pentane. The pale yellow product was collected on a frit and dried under reduced pressure. The yield was 0.8854 g (59.1%). ^{1}H NMR (C_6D_6) δ 7.06 (d, 2H), 6.87 (d, 2H), 2.50 (s, 3H), 2.47 (s, 3H), 2.21 (s, 3H), 1.89 (s, 3H), 1.88 (s, 3H), 0.51 (s, 3H), 0.41 (s, 3H). The structure was shown by x-ray crystallography to be a LiCl-containing dimer with bridging chlorides.

Example 92 Preparation of (Benzylamido)dimethyl(tetramethyl-η^5-cyclopenadienyl)silanetitanium dichloride.

(a) (Benzylamino)dimethyl(tetramethylcyclopentadienyl)silane

To a solution of 1.000 g (4.651 mmol) (chloro)(dimethyl)(tetramethylcyclopentadienyl)silane in 70 mL ether was slowly added 0.526 g (4.651 mmol) lithium benzylamide. The reaction mixture was stirred overnight, then the solvent was removed, the residue was extracted with pentane and filtered. The pentane was removed under reduced pressure to give the product as a pale yellow oil. The yield was 1.234 g (93.3%). Mass spec. m/e 285 (18%). ^{1}H NMR (C_6D_6) δ 7.0-7.24 (m, 5H), 3.71 (d, 2H), 2.73 (br, s, 1H), 1.88 (s, 6H), 1.76 (s, 6H), 0.43 (br t, 1H), -0.07 (s, 6H). ^{13}C NMR (C_6D_6) δ 144.5, 135.7, 132.0, 128.5, 127.3, 126.7, 56.7, 46.4, 14.6, 11.4, -2.3.

(b) Dilithium (benzylamido)dimethyl(tetramethylcyclopentadienyl)silane

To a solution of 1.091 g (3.836 mmol) (benzylamino)(dimethyl)(tetramethylcyclopentadienyl)silane in 70 mL ether was slowly added 3.1 mL of 2.60 M (8.06 mmol) butyl lithium in mixed C_6 alkane solvent. A pale pink color forms along with precipitate. The reaction mixture was stirred overnight. The solvent was removed under reduced pressure. The resulting solid was slurried in pentane, collected on a frit, washed with pentane and dried under reduced pressure to give the product as a very pale pink powder. The yield was 1.105 g (96.9%). ^{1}H NMR (THF d-8) d 7.15 (m, 4H), 7.00 (t, 1H), 4.02 (s, 2H), 2.04 (s, 6H), 1.79 (s, 6H), -0.15 (s, 6H). ^{13}C NMR (THF d-8) d 152.1, 128.1, 127.9, 125.0, 115.8, 111.9, 108.3, 54.0, 15.0, 11.2, 4.6.

(c) (Benzylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride

A slurry of 0.5052 g (1.699 mmol) dilithium (benzylamido)(dimethyl)(tetramethyl-η^5-cyclopentadienyl)-silane and 0.5673 g (1.699 mmol) $TiCl_4(THF)_2$ in 40 mL toluene was stirred for several days. The dark green-brown reaction mixture was filtered and the solvent was removed. The dark oily residue was slurried in pentane and the product was collected on a frit and washed with cold pentane to remove a dark oily material to give the product as a greenish yellow powder. Yield: 0.2742 g (40.1%). ^1H NMR (C_6D_6) δ 7.19 (m, 2H), 7.02 (m, 3H), 5.37 (s, 2H), 1.99 (s, 6H), 1.98 (s, 6H), 0.03 (s, 6H). ^{13}C NMR (C_6D_6) δ 141.4, 140.9, 135.8, 129.0, 128.8, 126.9, 126.6, 126.3, 111.6, 103.6, 59.3, 15.6, 12.4, 1.7.

Polymerization

The polymerization procedure of Example 80 was followed using 10 micromoles of the above complex. The polymer yield was 14.4 g, Mw = Mw/Mn = 5.0, melt index = 251, density = 0.9690.

Example 93 Preparation of (Benzylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanezirconium dichloride

In a flask were combined 0.3930 g (1.687 mmol) $ZrCl_4$, 0.5015 g (1.687 mmol) dilithium (benzylamido)-dimethyl(tetramethyl-η^5-cyclopenta dienyl)silane and 40 mL toluene. The brownish yellow slurry was stirred for several days then filtered and the solvent was removed under reduced pressure. The moist tan residue was slurried in pentane and the product was collected on a frit and dried under reduced pressure. Yield of the off-white tan product: 0.2873 g (38.2%). 1H NMR (C_6D_6) δ 7.51 (d, 2H), 7.23 (t, 2H), 7.09 (t, 1H), 5.48 (d, 1H), 5.00 (d, 1H), 2.45 (s, 6H), 2.05 (s, 3), 2.01 (s, 3H), 0.34 (s, 3H), 0.20 (s, 3H). ^{13}C NMR (C_6D_6) δ 145.2, 135.1, 132.2, 131.8, 129.4, 129.0, 128.9, 128.8, 127.0, 126.6, 126.3, 106.6, 57.2, 16.0, 15.6, 12.5, 11.8, 2.6.

Example 94 Preparation of (Phenylphosphino)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride

(a) (Phenylphosphino)(dimethyl)(tetramethylcyclopentadienyl)silane

To a solution of 1.500 g (6.983 mmol) (chloro)(dimethyl))tetramethylcyclopentadienyl)silane in 55 mL THF was slowly added 1.1248 g (7.665 mmol, excess added as GC monitoring indicated 1:1 reaction was incomplete) lithium phenylphosphide (0.4 ether adduct by ^1H NMR spectroscopy). The reaction mixture was stirred several days, then the solvent was removed, the residue was extracted with pentane and filtered. The pentane was removed under reduced pressure to give the product as a yellow oil. The yield was 1.985 g (98.5%).

(b) Dilithium (phenylphosphido)dimethyl(tetramethylcyclopentadienyl)silane

To a solution of 1.858 g (6.451 mmol) (phenylphosphino)(dimethyl)(tetramethylcyclopentadienyl) silane in 65 mL ether was slowly added 5.21 mL of 2.60 M (13.55 mmol) butyllithium in mixed C_6 alkane solvent with the formation of a yellowish precipitate. The reaction mixture was stirred overnight. The product was collected on a frit and washed with pentane, then dried under reduced pressure to give the product as a white powder. The yield (0.5 ether adduct by ^1H NMR spectroscopy) was 2.0845 g (95.8%).

(c) (Phenylphosphido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride

In a flask w r combined 0.900 g (2.668 mmol) dilithium (phenylphosphido)(dimethyl)(tetramethyl-η^5-cyclopentadienyl)silane (0.5 ether adduct) and 0.8907 g (2.668 mmol) TiCl4(THF)2 with 75 mL toluene. Th color instantly changed to deep green-black on addition of toluene. The reaction mixture was stirred for several days, then was filtered and the solvent was removed. The dark residue was extracted with pentane

and filtered to leave a green-brown product on the frit (0.2477 g) and a black glassy product on removal of the pentane from the filtrate.

Polymerization

The polymerization procedure of Example 80 was followed using 10 micromoles of the above complex. The polymer yield was 14.4 g, Mw = 27,700, Mw/Mn = 5.0, melt index = 251, density = 0.9690.

Example 95 Preparation of (Phenylphosphido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanezirconium dichloride

To 0.6217 g (2.668 mmol) $ZrCl_4$ in a flask was slowly added 3 mL diethyl ether. The excess solvent was removed under vacuum to yield a solid which was broken up to a powder. The solid was combined with 0.9000 g (2.668 mmol) dilithium (phenylphosphido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silane and 75 mL toluene. The color changed to deep red-orange on addition of toluene. The reaction mixture was stirred for several days, then the orange solution was filtered from a large quantity of dark insoluble material and the solvent was removed. The residue was slurried with pentane and filtered. A brown solid was collected on a frit and dried under reduced pressure.

Example 96 Preparation of (Tert-butylamido)dimethyl(indenyl)silanetitanium dichloride

(a) (Tert-butylamino)dimethyl(indenyl)silane

To a solution of 5.255 g (71.8 mmol) tert-butyl amine in 75 mL ether was added 3.000 g (14.4 mmol) 9-(chlorodimethylsilyl)indene. Precipitate formed within a few minutes of the start of the addition. The slurry was stirred overnight, then the solvent was removed, the residue was extracted with pentane and filtered. The pentane was removed under reduced pressure to give the light-yellow oil product as a mixture of two isomers. The yield was 3.313 g, (93.9%).

(b) Dilithium (tert-butylamido)dimethyl(indenyl)silane

To a solution of 3.125 g (12.73 mmol) (tert-butylamino)dimethyl(indenyl)silane in 75 mL ether was slowly added 10.28 mL of 2.60 M (26.73 mmol) butyl-lithium in mixed C_6 alkane solvent. The color of the precipitate-free solution darkens slightly to beige-orange. The reaction mixture was stirred several days, then the solvent was removed. The fluffy, glassy material was slurried with pentane. The powder clumps together. The pentane was decanted and the washing procedure was repeated several times, then the solid was dried under reduced pressure. The yield was 2.421 g (73.9%).

(c) (Tert-butylamido)dimethyl(indenyl)silanetitanium dichloride

In a flask were combined 1.000 g (3.887 mmol) dilithium (tertbutylamido)(dimethyl)(indenyl)silane and 1.298 g (3.887 mmol) $TiCl_4(THF)_2$ with 70 mL toluene. A deep red color developed instantly. The reaction mixture was stirred three days, then filtered, and the solvent was removed. The residue was extracted with pentane and filtered to give the product as a red microcrystalline material. The yield was 0.4917 g (34.9%).

Polymerization

The polymerization procedur of Example 80 was followed using 10 micromoles of the above complex. The polymer yield was 14.8 g.

Example 97 Preparation of (Tert-butylamido)dimethyl(indenyl)silanezirconium dichloride

To 0.9057 g (3.887 mmol) $ZrCl_4$ in a flask was slowly added 2 mL THF. The excess THF was removed under vacuum to yield a solid which was broken up to a powder. 1.000 g (3.887 mmol) dilithium (tertbutylamido)dimethyl(indenyl)silane was added along with 70 mL toluene. The resulting slurry was stirred for several days after which the solution was filtered and the solvent removed under reduced pressure. The residue was slurried in pentane, filtered and dried under reduced pressure. The yield of brown-biege product was 0.5668 g (36.0%).

Example 98 Preparation of (Methylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride

(a) (Methylamino)dimethyl(tetramethyl-η^5-cyclopentadienyl)-silane

To a solution of 1.900 g (8.845 mmol) (chloro)(dimethyl)(tetramethylcyclopentadienyl)silane in 75 mL THF was quickly added 0.3272 g (8.846 mmol) lithium methylamide. The clear solution was stirred overnight, then additional lithium methylamide (0.008 g, 9.062 mmol total) was added as gas chromatography (GC) indicated the reaction was incomplete and the solution was stirred overnight again. The solvent was removed, the residue was extracted with pentane and filtered, and the pentane was removed under reduced pressure to give the product as a very pale yellow oil. The yield was 1.698 g (91.7%). Mass spec. m/e 209 (13 percent). ^1H NMR (C_6D_6): δ 2.82 (s, 1H), 2.33 (d, J = 6.6 Hz, 3H), 1.95 (s, 6H), 1.83 (s, 6H), -0.04 (s, 6H). ^{13}C NMR (C_6D_6: δ 135.4, 132.7, 56.1, 27.8, 14.0, 11.0, -3.5.

(b) Dilithium(methylamido)dimethyl(tetramethylcyclopentadienyl)silane

To a solution of 1.563 g (7.463 mmol) (methylamino)(dimethyl)(tetramethylcyclopentadienyl) silane in 65 mL ether/pentane (1:1) was slowly added 6.03 mL of 2.60 M (15.7 mmol) butyllithium in mixed C_6 alkane solvent. The solution turned to a thick syrup which broke down to a slurry. The reaction mixture was stirred overnight, then filtered. The solid was washed several times with ether, then with pentane, then dried under reduced pressure to give the product as a white powder. The yield was 1.883 g of a 0.25 ether adduct as determined by ^1H NMR spectroscopy. ^1H NMR (THF δ-8) δ 3.41 (q,J = 7.0 Hz, 1H), 2.45 (s, 3H), 2.01 (s, 6H), 1.93 (s, 6H), 1.11 (t, J = 7.01, .5H), 0.01-0.14 (br, 6H).

(c) (Methylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride

To a solution of 0.6708 g (2.597 mmol) dilithium (methylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silane in 80 mL THF was added all at once 0.9623 g (2.597 mmol) $TiCl_3(THF)_3$. The solution immediately turned intense brown-orange. The reaction mixture was stirred four days, then 1.861 g (12.98 mmol) AgCl was added. The slurry was stirred several days after which the reaction mixture was filtered and the solvents were removed under reduced pressure. The residue was extracted with toluene, the dark orange- brown solution was filtered and the solvent was removed. After extraction with pentane and filtration, the filtrate was concentrated to a light brown slurry in a dark red solution. After cooling to -30° C, the bright yellow product was collected on a frit, washed with pentane and dried under reduced pressure. The yield was 0.3168 g (37.4%). ^1H NMR (C_6D_6): δ 3.64 (s,3H), 1.97 (s, 6H), 1.95 (s, 6H), 0.21 (s, 6H). ^{13}C NMR (C_6D_6): δ 140.5, 135.5, 103.0, 41.8, 15.5, 12.3, 0.6.

Polymerization

The polymerization procedure of Example 80 was followed using 10 micromoles of the above complex. The polymer yield was 30.2 g.

Example 99 Preparation of (Methylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanezirconium dichloride

In a flask 0.5705 g (2.448 mmol) $ZrCl_4$ and 0.6318 g (2.446 mmol) dilithium (methylamido)dimethyl-(t tramethyl-η^5-cyclopentadienyl)silane were combined with 75 mL toluene. The slurry was stirred for several days after which time the resulting pale green solution was filtered, and the solvent was removed under reduced pressure. The residue was slurried in pentane, collected on a frit, washed with pentane and dried under reduced pressure. The yield of very pale powder blue product was 0.6162 g (68.2%). ^1H NMR (C_6D_6): δ 3.50 (s, 3H), 2.49 (s, 3H) 2.36 (s, 3H), 2.14 (s, 3H), 2.10 (s, 3H), 0.46 (s, 3H), 0.43 (s, 3H).

Example 100 Preparation of 1-(Tert-butylamido)-2-(tetramethyl-η^5-cyclopentadienyl)ethanediyltitanium dichloride

(a) Ethyl 2-(tetramethylcyclopentadienyl)acetate

A solution of 3.822 g (22.89 mmol) ethyl bromoacetate in 25 mL THF was cooled to -78 °C and 3.000 g (20.80 g) sodium tetramethylcyclopentadienide in 50 mL THF was slowly added to it. The resulting slurry was allowed to warm to room temperature and was stirred overnight. The solvent was removed, the residue was extracted with pentane and filtered. The pentane was removed to give a mixture of isomers. Yield was 3.733 g (86.3%). Mass spectra m/e 208 (41 percent).

(b) 2-(Tetramethylcyclopentadienyl)tert-butyl acetamide

16.35 mL of 2.00 M (32.7 mmol) trimethyl aluminum in toluene was added to 2.39 g (32.7 mmol) tert-butylamine in 50 mL toluene. The solution was stirred for 45 minutes, then 3.40 g ethyl-2-tetramethyl-cyclopentadienyl acetate was added. The reaction mixture was stirred for several days while gently warming. After aqueous workup the product amide was obtained as a mixture of three isomers as an orange semicrystalline paste. Mass spectra m/e 235 (21%).

(c) 1-(tert-butylamino)-2-(tetramethylcyclopentadienyl)ethane

The amide mixture was dissolved in 120 mL ether and 0.830 g (21.8 mmol) lithium aluminum hydride was added. The reaction mixture was stirred overnight under gentle heating. Monitoring by GC indicated the reaction was incomplete. The ether was replaced by THF, more lithium aluminumhydride was added and the solution was refluxed for several days. After aqueous workup three 1-(tert-butylamino)-2-(tetramethylcyclopentadienyl)ethane isomers were obtained. Mass spectra m/e 221 (11%).

(d) Dilithium 1-(tertbutylamido)-2-(tetramethyl-η^5-cyclopentadienyl)ethane

To a solution of 2.00 g (9.05 mmol) (tert-butylamino)-2-(tetramethylcyclopentadienyl)ethane isomers (67 percent 1-(tertbutylamino)-2-(2,3,4,5-tetramethylcyclopentadi-2,4-enyl)ethane by GC, 1.34 g (6.06 mmol)) in 50 mL ether was slowly added 6.09 mL of 2.60 M (15.8 mmol) butyllithium in mixed C_6 alkane solvent with formation of a yellow precipitate. The reaction mixture was stirred three days, then filtered. The light yellow powder was washed several times with ether, then dried under reduced pressure. The yield was 0.7908 g (55.9%). ^1H NMR (THF d-8): δ 2.43 (br m, 4H), 1.85 (s, 6H), 1.83 (s, 6H), 1.00 (s, 9H). ^{13}C NMR (THF d-8): δ 109.5, 107.3, 106.3, 50.5, 45.4, 29.4, 28.2, 20.2, 10.9, 10.8.

(e) 1-(Tert-butylamido)-2-(tetramethyl-η^5-cyclopentadienyl)ethanediyltitanium dichloride

In a flask 0.3650 g (1.565 mmol) dilithium 1-tert-butylamido)-2-(tetramethylcyclopentadienyl)ethane and 0.5799 g (1.565 mmol) $TiCl3(THF)_3$ were combined with 60 mL THF. The solution quickly turned green. The reaction mixture was stirred ov rnight, then 1.121 g (7.82 mmol) AgCl was add d. Within a f w minutes the color began to change to brownish orange. The slurry was stirred two days and the solvents were removed under reduced pressure. The residue was extracted with toluene, the solution was filtered and the solvent was removed. The residue was extracted with pentane, filtered, concentrated, and cool d to -30 °C. The

bright orange product was collected on a frit, washed with a small amount of cold pentane and dried under reduced pressure. The yield was 0.1904 g (36.0%). ^{1}H NMR (C_6D_6): δ 4.01 (t, J = 7.2, 2H), 2.58 (t, J = 7.2, 2H), 2.02 (s, 6H), 1.89 (s, 6H), 1.41 (s, 9H). ^{13}C NMR (C_6D_6): δ 138.0, 129.3, 128.6, 69.1, 62.7, 28.6, 24.9, 13.0, 12.3.

Polymerization 1

The polymerization procedure of Example 80 was followed using 10 micromoles of the above complex. The polymer yield was 64.8 g, melt index = 3.21, density = 0.9262.

Polymerization 2

The above polymerization procedure was repeated excepting that 0.95 micromoles of 1-(tert-butylamido)-2-tetramethyl-η^5-cyclopentadienyl)ethanediyltitanium dichloride was added to begin the polymerization. The polymer yield was 11.4 g, melt index <0.1, density = 0.9119.

Polymerization 3

The above polymerization procedure was repeated excepting that 2.5 micromoles of 1-(tert-butylamido)-2-(tetramethyl-η^5-cyclopentadienyl)ethanediyltitanium dichloride was added to begin the polymerization. In addition, 300 mL of octene and 900 mL of isopar was used, and no hydrogen was used. The polymer yield was 36.2 g, melt index = 0.21, density = 0.9190.

Polymerization 4

The conditions of above polymerization 1 were repeated excepting that the temperature was 90 °C. The polymer yield was 66.7 g, melt index = 0.16.

Example 101 Preparation of 1-(Tert-butylamido)-2-(tetramethyl-η^5-cyclopentadienyl)ethanediylzirconium dichloride

In a flask 0.3862 g (1.657 mmol) $ZrCl_4$ and 0.3866 g (1.657 mmol) dilithium [1-(tert-butylamido)-2-(tetramethyl-η^5-cyclopentadienyl)ethane] were combined with 50 mL toluene. After stirring several days, 1 mL THF was added and the slurry was stirred for an additional day after which time the solution was filtered, and the solvent was removed under reduced pressure. The solid was slurried in pentane, collected on a frit, and dried under reduced pressured. Yield of pale yellow product was 0.6307 g (99.8%). ^{1}H NMR (C_6D_6): δ 2.75 (t of d, 1H), 2.38 (m, 2H), 2.11, (s, 6H) 2.03 (s, 3H), 2.00 (s, 3H), 1.75 (t of d, 1H), 1.08 (s, 9H). ^{13}C NMR (C_6D_6): δ 131.5, 128.7, 126.8, 126.5, 126.2, 56.9, 50.9, 27.9, 23.1, 13.4, 13.2, 12.6, 12.5.

Example 102 Terpolymer Polymerization

Mixtures of ethylene, styrene and another additional polymerizable monomer were polymerized using (tert-butylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride complex and MAO cocatalyst in an amount to provide an atomic ratio Al/Ti of 1000:1. Reaction conditions and results are contained in Table VI.

Table VI

In each case the cocatalyst was methylaluminoxane and the metal complex was (tert-butylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)titanium dichloride.

Run	mg (complex)	T (°C)	Solvent (mL)[a]	Ethylene kPa (psig)	Styrene (mL)	Olefin (g)	Time (hr)	Yield (g)	mol% Styrene	mol% Olefin	M_w	M_w/M_n
1	1.8	90	I (670)	1515 (220)	38	butene (19)	0.5	51	2.3	6.6	141,000	2.9
2	1.9	90	I (630)	1515 (220)	76	butene (9)	0.5	45	3.4	4.5	155,000	2.4
3	1.9	90	I (455)	1515 (220)	250	butene (5)	0.5	70	7.2	3.2	153,000	2.4
4	2.2	90	T (40)	1240 (180)	153	Vinyl-BCB (1.5)[b]	2.0	37	22.4	<1	39,000	1.7

a. I = mixed alkane solvent, T = toluene

b. Vinyl-BCB = vinyl benzocyclobutane

Example 103 Slurry Polymerization

The following example demonstrates the use of a catalyst of the present invention under slurry conditions. The procedure of Examples 11-32 was substantially followed, excepting that the reaction was run under conditions where the polymer was insoluble in the reaction medium and precipitated from the reaction mixture as it formed. The temperature was 70 °C, 10 mL of octene, 1190 mL of mixed alkane solvent, and 5 mL of 15 percent MAO in toluene (1280 Al:Ti) were used. After 20 minutes, the reactor was drained to give 4.6 g of polymer. Additional solvent was added to the reactor and heated to 170 °C to remove the polymer that had formed long filaments and wound around the stirrer. The melt index was 0.28.

Example 104 Preparation of (Tert-butylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanetitanium(III) chloride

In the drybox, 0.24 g of $TiCl_3(THF)_3$ and 0.33 g of $Me_4C_5SiMe_2N$-t-$BuMg_2Cl_2(THF)_2$ were mixed. 15 mL Of THF was added, resulting in a deep purple color. After 30 minutes the volatile materials were removed under reduced pressure to leave a dark solid. Toluene (15 mL) was added, the solution filtered, and the toluene was removed under reduced pressure to leave a red-purple powder, 0.22 g.

Polymerization

The polymerization procedure of Example 80 was followed using 10 micromoles of the above complex. The polymer yield was 55.1 g, melt index = 1.71.

Example 105

The polymerization procedure of Example 80 was followed using 10 micromoles of (tert-butylamido)-dimethyl(tetramethyl-η^5-cyclo pentadienyl)silanetitanium dichloride. The polymer yield was 76.4 g, Mw = 56,700, Mw/Mn = 4.5, density = 0.8871, melt index (I_2) = 10.13.

Example 106

The polymerization procedure of Example 105 was substantially followed except that the temperature was 80 °C, the amount of catalyst used was 2.5 micromoles, the amount of 1-octene used was 250 mL, and the amount of mixed alkane solvent used was 950 mL. The reaction was allowed to proceed for 1 hour. The polymer yield was 51.1 g. The melt index was 0.11.

Example 107 Preparation of (Tert-butylamido)dimethyl(tetramethylcyclopentadienyl)silanehafnium dichloride

In the drybox, 0.50 g of $HfCl_4$ was suspended in 110 mL of toluene. 10 mL Of THF was added, the slurry was stirred for 5 minutes, and 0.77 g of $Me_4C_5SiMe_2N$-t-$BuMg_2Cl_2(THF)_2$ was added. THe solution was heated to reflux. After 30 minutes, the solution was cooled, and the volatile materials were removed under reduced pressure. Pentane (20 mL) was added, the solution was filtered, and the pentane was removed under reduced pressure to leave a white solid. This solid was washed with a small quantity of pentane to yield 0.077 g (10%) of a white solid, 1H NMR (C_6D_6): δ 2.08 (6H), 1.30 (9N), 0.44 (6H).

Wh n ethylene was polymerized substantially according to the procedur of Example 7, a small amount of polyethylene was recovered.

Comparative 1

The polymerization procedure of Example 105 was followed except that the catalyst was pentamethylcyclopentadienyltitanium trichloride. The polymer yield was 4.6 g.

Comparative 2

The polymerization procedure of Example 97 was followed except that the catalyst was (tert-butylamido)pentamethyl-η^5-cyclopentadienyltitanium dichloride (^1H NMR (C_6D_6): δ 2.07 (s, 1H), 1.88 (s, 15H), 1.35 (s, 9H). ^{13}C NMR (C_6D_5): δ 61.0, 31.3, 12.6). The polymer yield was 2.0 g.

Comparative 3

The polymerization procedure of Example 105 was followed except that the catalyst was bis-(tert-butylamido)dimethylsilanetitanium dichloride. No polymer was observed after 10 minutes of reaction.

Comparative 4

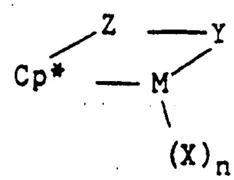
The polymerization procedure of Example 105 was followed except that the catalyst was dicyclopentadienylzirconium dichloride. The polymer yield was 109.0 g, Mw = 16,300, Mw/Mn = 3.63, melt index ASTM D-1238 Procedure A, condition E, I_2, was greater than 1,000 indicating a very low molecular weight polymer.

Comparative 5

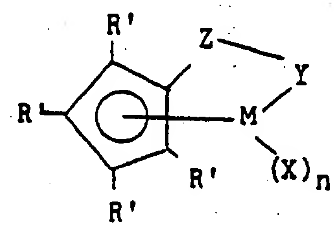
The polymerization procedure of Example 105 was followed except that the catalyst was dicyclopentadienyltitanium dichloride. The polymer yield was 7.3 g, melt index, ASTM D-1238 Procedure A, condition E, I_2, was greater than 1,000 indicating a very low molecular weight polymer.

Claims

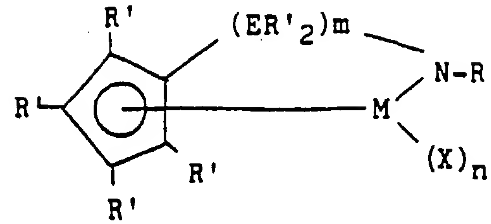
1. A metal coordination complex comprising a metal of Group 3 (other than scandium), 4-10 or the lanthanide series of the Periodic Table of the Elements and a delocalized Π-bonded moiety substituted with a constrain-inducing moiety, said complex having a constrained geometry about the metal atom such that the angle at the metal between the centroid of the delocalized, substituted Π-bonded moiety and the center of at least one remaining substituent is less than such angle in an comparative complex differing only in that said constrain-inducing substituent is replaced by hydrogen, and provided further that for such complexes comprising more than one delocalized, substituted Π-bonded moiety, only one thereof for each metal atom of the complex is a cyclic, delocalized, substituted Π-bonded moiety.
2. A metal coordination complex as claimed in Claim 1, wherein said delocalized Π-bonded moiety is an alkene, alkenyl, alkyne, alkynyl, allyl, polyene or polyenyl moiety.
3. A metal coordination complex as claimed in Claim 1, wherein said delocalized Π-bonded moiety is a cyclic moiety.
4. A metal coordination complex as claimed in Claim 3, wherein said cyclic moiety is cyclopentadienyl or substituted cyclopentadienyl moiety.
5. A metal coordination complex as claimed in Claim 3 or Claim 4, wherein said cyclic moiety forms part of a ring structure in which said metal is both bonded to an adjacent covalent moiety and held in association with said cyclic moiety.
6. A metal coordination complex corresponding to the formula:



wherein:
M is a metal of Group 3 (other than scandium), 4-10, or the lanthanide series of the Periodic Table of the Elements;
Cp* is a cyclopentadienyl or substituted cyclopentadienyl group bound in an η^5 bonded mode to M;
Z is a moiety comprising boron, or a member of Group 14 of the Periodic Table of the Elements and optionally sulfur or oxygen, said moiety having up to 20 non-hydrogen atoms, and optionally Cp* and Z together form a fused ring system;
X each occurrence is an anionic ligand group or neutral Lewis base ligand group having up to 30 non-hydrogen atoms;
n is 0, 1, 2, 3 or 4 depending on the valance of M; and
Y is an anionic or nonanionic ligand group bonded to Z and M comprising nitrogen, phosphorus, oxygen or sulfur and having up to 20 non-hydrogen atoms, and optionally Y and Z together form a fused ring system.
7. A metal coordination complex as claimed in Claim 6, wherein the substituted cyclopentadienyl group is cyclopentadienyl substituted by one or more C_{1-20} hydrocarbyl, C_{1-20} halohydrocarbyl, halogen or C_{1-20} hydrocarbyl-substituted Group 14 metalloid or is indenyl, tetrahydroindenyl, fluorenyl or octahydrofluorenyl.
8. A metal coordiantion complex as claimed in Claim 6 or Claim 7, wherein each X is hydride, halo, alkyl, sily, germyl, aryl, amide, aryloxy, alkoxy, siloxy, phosphide, sulfide, acyl, cyanide, azide or acetylacetonate.
9. A metal coordination complex as claimed in Claim 6 corresponding to the formula:



whrein R′ each occurrence is hydrogen or a moiety selected from alkyl, aryl, silyl, germyl, cyano, halo, or a combination thereof having up to 20 non-hydrogen atoms or an adjacent pair of R′ groups form a hydrocarbyl ring fused to the cyclopentadienyl moiety;
X each occurrence is hydride or a moiety selected from halo, alkyl, silyl, germyl, aryl, amide, aryloxy, alkoxy, siloxy and combinations thereof having up to 20 non-hydrogen atoms and neutral Lewis base ligands having up to 20 non-hydrogen atoms;
Y is -O-, -S-, -NR*-, -PR*-, or a neutral two electron donor ligand selected from of OR*, SR*, NR^*_2, or PR^*_2;
M is as previously defined; and
Z is SiR^*_2, CR^*_2, $SiR^*_2SiR^*_2$, $CR^*_2CR^*_2$, CR* = CR*, $Cr^*_2SiR^*_2$, GeR^*_2, BR*, BR^*_2;
R* each occurrence is hydrogen or a moiety selected from alkyl, aryl, silyl, halogenated alkyl, halogenated aryl groups, and combinations thereof having up to 20 non-hydrogen atoms or two or more R* groups from Y, Z, or both Y and 2 form a fused ring system.
10. A metal coordination complex as claimed in Claim 9, wherein Y is an amido or phosphido group corresponding to the formula -N″- or -PR″-, wherein R″ is C_{1-10} alkyl or aryl.
11. A metal coordination complex as claimed in Claim 10 which is an amidosilane or amidoalkanediyl compound corresponding to the formula:



wherein:
M is titanium, zirconium or hafnium, bound in an η^5 bonding mode to the cyclopentadienyl group;
R′ each occurrence is hydrogen or a moiety selected from silyl, alkyl, aryl, or combinations thereof having up to 10 carbon or silicon atoms;
E is silicon or carbon;
X each occurrence is hydride, halo, alkyl, aryl, aryloxy, or alkoxy of up to 10 carbons;
m is 1 or 2; and
n is 1 or 3 depending on the valence of M.

12. A metal coordination complex as claimed in Claim 11, wherein each R′ is hydrogen, C_{1-6} alkyl, norbornyl, benzyl or phenyl or R′ on the cyclopentadienyl moiety form with said moiety an indenyl, tetrahydroindenyl, fluorenyl or octahydrofluorenyl group; and X is chloro, bromo, iodo, C_{1-6} alkyl, norbornyl, benzyl or phenyl.

13. A metal coordination complex as claimed in any one of Claims 1-5, wherein said angle is decreased by at least 5 percent compared with said comparative complex.

14. A metal coordination complex as claimed in Claim 13, wherein said angle decrease is at least 7.5 percent.

15. A metal coordination complex as claimed in Claim 13 or Claim 14, wherein said metal is a metal of Group 4 or lanthanide metal and said angle is less than 115°.

16. A metal coordiantion complex as claimed in Claim 15, wherein said angle is less than 105°.

17. A metal coordination complex as claimed in any one of Claims 1 to 10 and 13 to 16, wherein said metal is of Group 4 or lanthanide metal.

18. A metal coordination catalyst as claimed in Claim 17, wherein said metal is titanium, zirconium or hafnium.

19. A metal coordination complex selected from (tert-butylamido) (tetramethyl-η^5-cyclopentadienyl)-1,2-ethanediylzirconium dichloride, (tert-butylamido)-(tetramethyl-η^5-cyclopentadienyl)-1,2-ethanediyltitanium dichloride, (methylamido)-(tetramethyl-η^5-cyclopentadienyl)-1,2-ethanediyl-zirconium dichloride, (methylamido)(tetramethyl-η^5-cyclopentadienyl)-1,2-ethanediyltitanium dichloride, (ethylamido)(tetramethyl-η^5-cyclopentadienyl)-methylenetitanium dichloride, (tert-butylamido)dimethyl-(tetramethyl-η^5-cyclopentadienyl)silanetitanium dichloride, (tert-butylamido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanezirconium dibenzyl, (benzylamido)dimethyl(tetramethyl-η^5- cyclopentadienyl)silanetitanium dichloride, and (phenylphosphido)dimethyl(tetramethyl-η^5-cyclopentadienyl)silanezirconium dibenzyl.

20. A catalyst useful in addition polymerizations comprising
a) a metal coordination complex as claimed in any one of the preceding claims, and
b) an activating cocatlyst.

21. A catalyst as claimed in Claim 20, wherein said activing cocatalyst comprises an aluminum compound.

22. A catalyst as claimed in Claim 21, wherein said aluminum compound is an alkylaluminoxane, aluminum alkyl, aluminum halide, or aluminum alkylhalide.

23. A catalyst as claimed in Claim 20, wherein said activating cocatalyst comprises a Lewis acid, ammonium salt, or noninterfering oxidizing agent.

24. A catalyst as claimed in Claim 21, wherein the activating cocatalyst is selected from alkylaluminoxanes, and compounds corresponding to the formula:
$ALR_nX''_{3-n}$
wherein:
R is each occurrence C_{1-10} alkyl or aralkyl;
X″ is halogen; and
n is 1, 2 or 3.

25. A process for preparing a metal coordination complex as claimed in Claim 6 comprising.
(a) contacting a metal compound of the formula MX_{n+2} or MX_{n+1}, or a coordinated adduct ther of with a dianionic salt compound corr sponding to the formula:

$(L+x)y(Cp^{*}\text{-}Z\text{-}Y)^{-2}$ or $(LX'')+x)y(Cp^{*}\text{-}Z\text{-}Y)^{-2}$
wherein:
n, Cp*, M, X, Y, and Z are as defined in Claim 6;
L is a metal of Group 1 or 2 of the Periodic Table of the Elements,
x and y are either 1 or 2 and the product of x and y equals 2, and
X'' is fluoro, bromo, chloro or iodo,
in an inert aprotic solvent, and, when the metal compound is of the formula MX_{n+1};
(b) contacting the product of (a) with a noninterfering oxidizing agent to raise the oxidation state of the metal.

26. A process for preparing a catalyst as claimed in Claim 20, comprising contacting a complex as defined in Claim 1 or Claim 6 with an activating cocatalyst.

27. An addition polymerization process for preparing a polymer by contacting one or more addition polymerizable monomers with a catalyst under addition polymerization conditions characterized in that the catalyst is as defined in any one of Claims 20 to 24.

28. A process as claimed in Claim 27, wherein the addition polymerizable monomers are selected from ethylenically unsaturated monomers, acetylenic compounds, conjugated or nonconjugated dienes, and polyenes having from 2 to 20 carbons, and carbon monoxide.

29. A process as claimed in Claim 27, wherein an alpha olefin is copolymerized with a vinylidene aromatic or hindered aliphatic vinyl monomers.

30. A process as claimed in Claim 29, wherein ethylene is copolymerized with a styrene or a vinylcyclohexene.

31. A copolymer comprising ethylene and an olefin other than ethylene obtainable by a process as defined in Claim 27 and having a melt index less than 200 ((I_2), ASTM D-1238 Procedure A, condition E) and an elastic modulus greater than 1000 dyne/cm^2.

32. A copolymers as claimed in Claim 31, wherein the olefin other than ethylene is propylene, isobutylene, 1-butene, 1-hexane, 4-methyl-1-pentene or 1-octene.

33. A pseudo-random polymer comprising an interpolymer of an olefin and a vinylidene aromatic monomer and obtainable by a process as defined in Claim 27.

34. A polymer as claimed in Claim 33, comprising ethylene and a styrene.

35. A pseudo-random polymer comprising an interpolymer of hindered aliphatic vinylidene compound and an alph-olefin and obtainable by a process as claimed in Claim 27.

36. A polymer as claimed in Claim 35, comprising ethylene and a vinylcyclohexane.

FIG.1

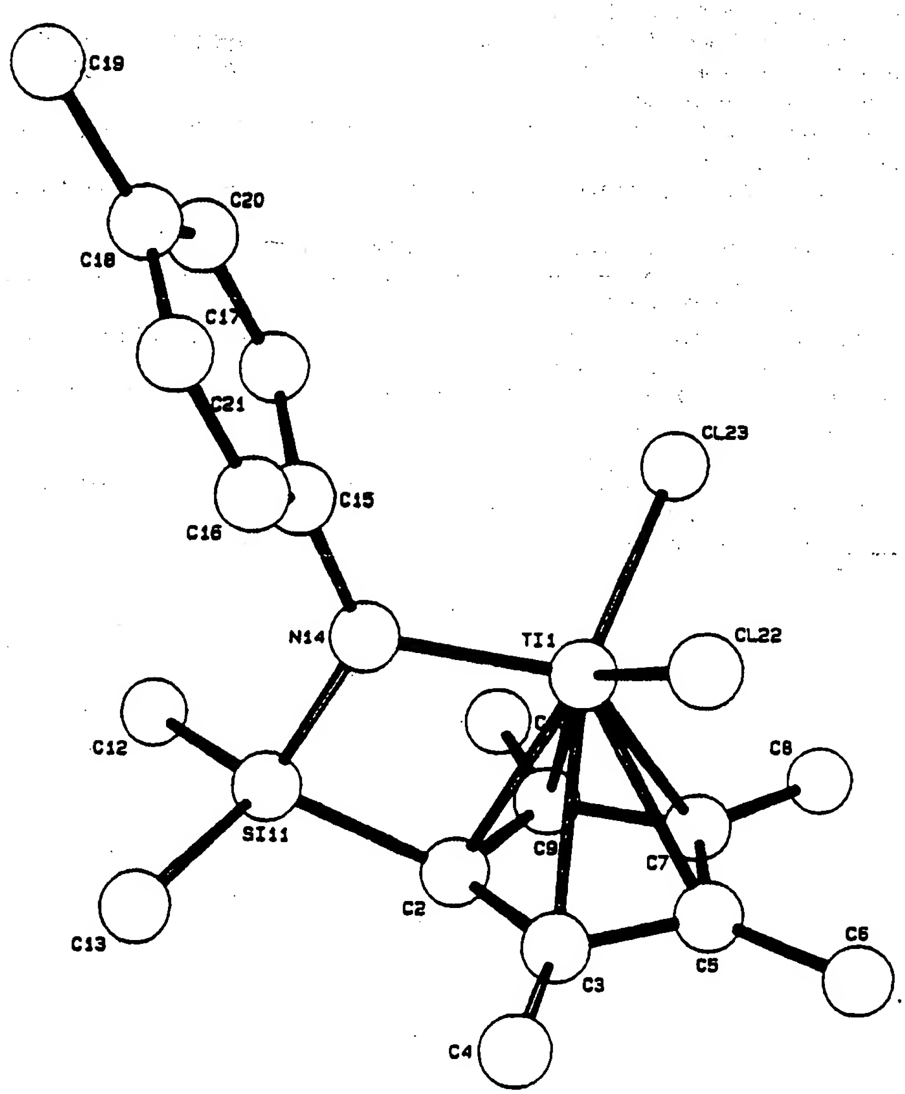

C19
C20
C18
C17
C21
CL23
C15
C16
N14
TI1
CL22
C12
C8
SI11
C9
C7
C2
C6
C13
C5
C3
C4

FIG.2

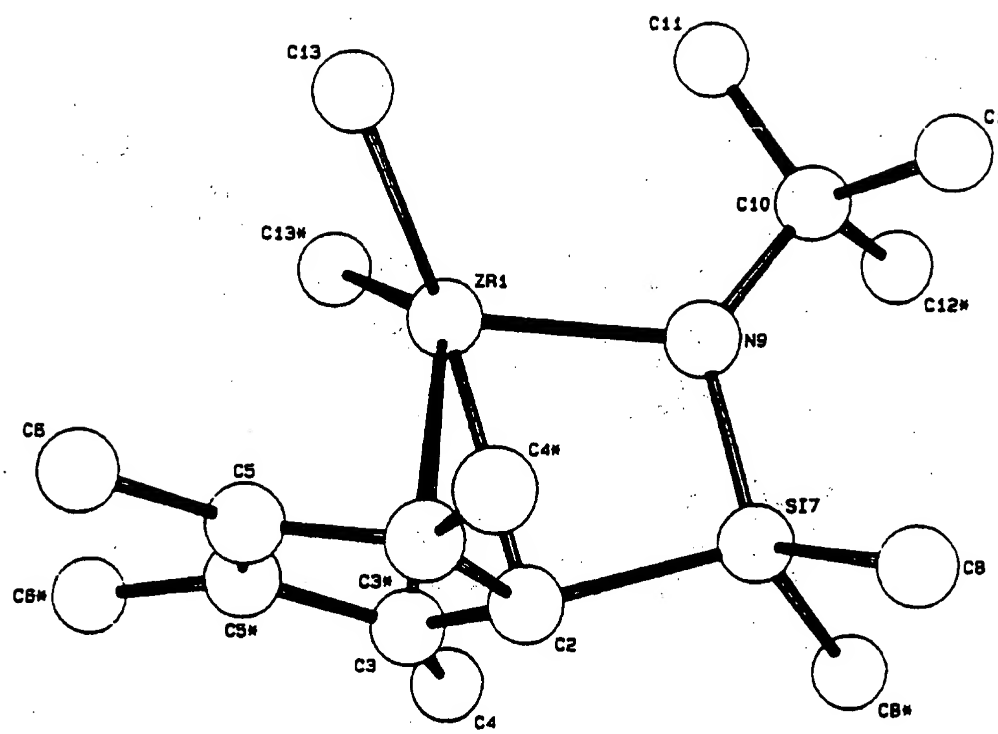


FIG.3

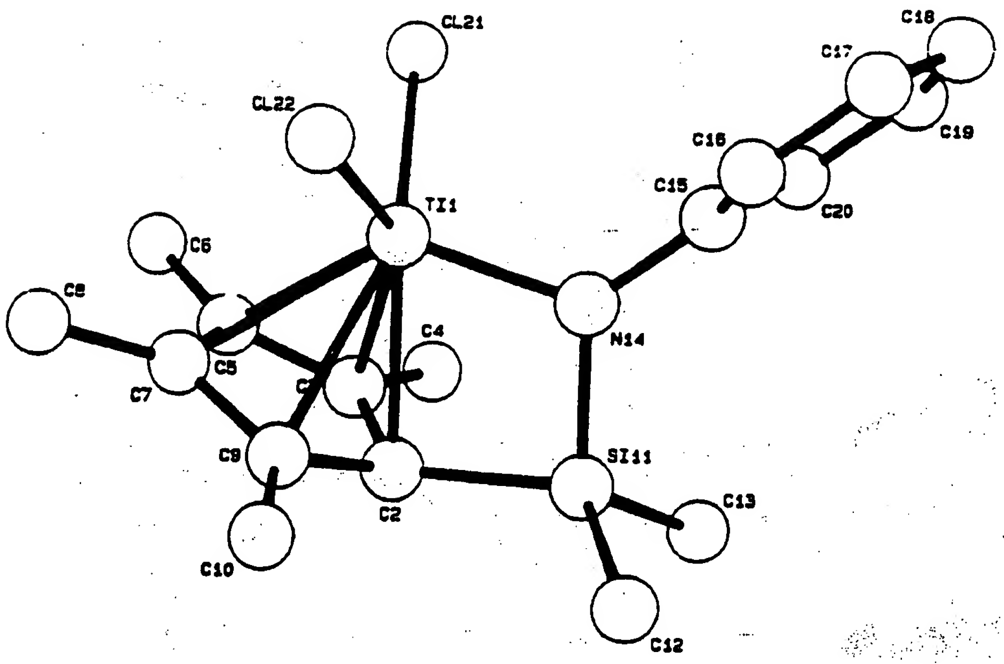

CL21
CL22
TI1
C6
C8
C5
C7
C4
C3
C9
C2
C10
N14
SI11
C13
C12
C15
C16
C20
C17
C18
C19

FIG.4

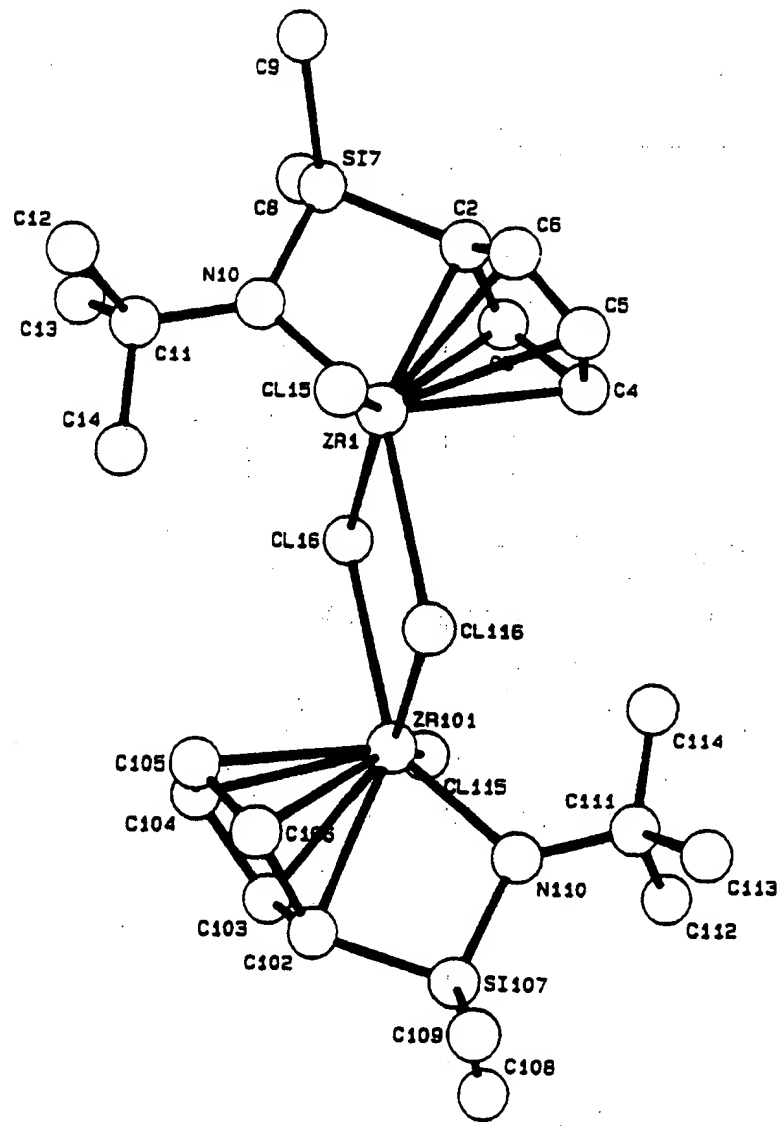

C9
SI7
C8
C2
C6
C12
N10
C5
C13
C11
C4
CL15
C14
ZR1
CL16
CL116
ZR101
C114
C105
CL115
C111
C104
C103
N110
C113
C112
C102
SI107
C109
C108

FIG.5

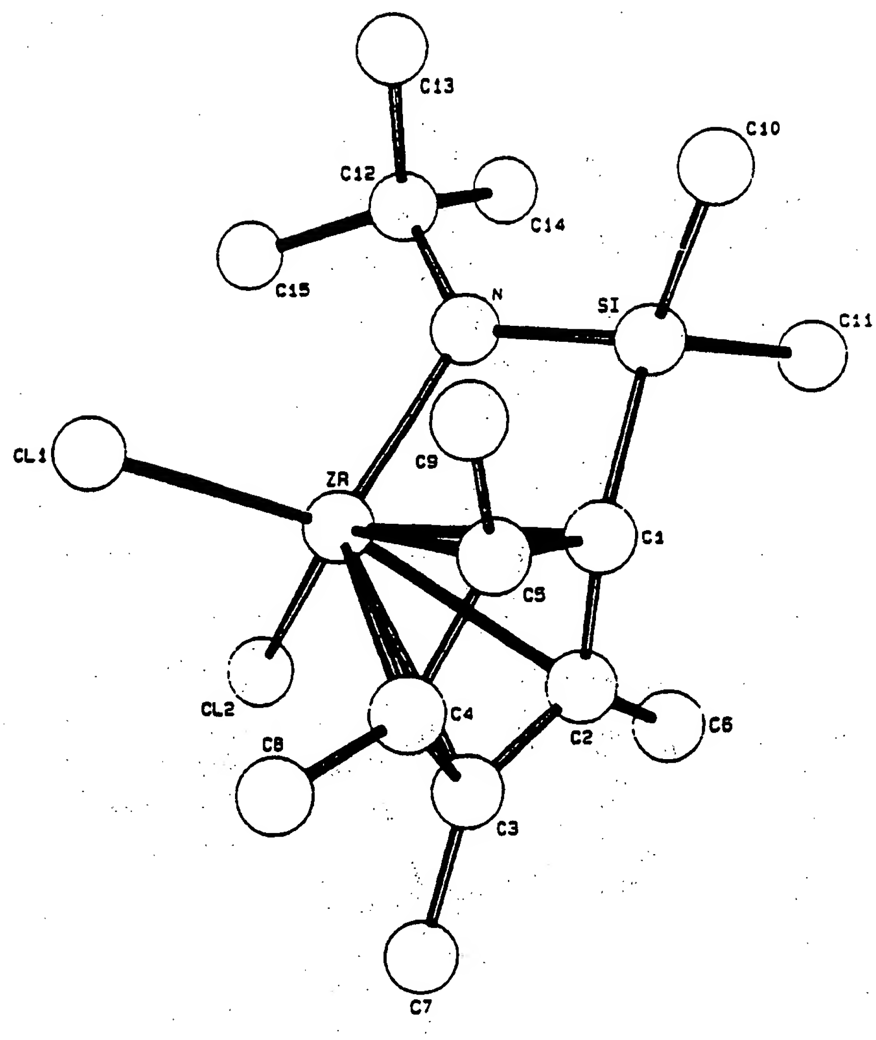


FIG. 6

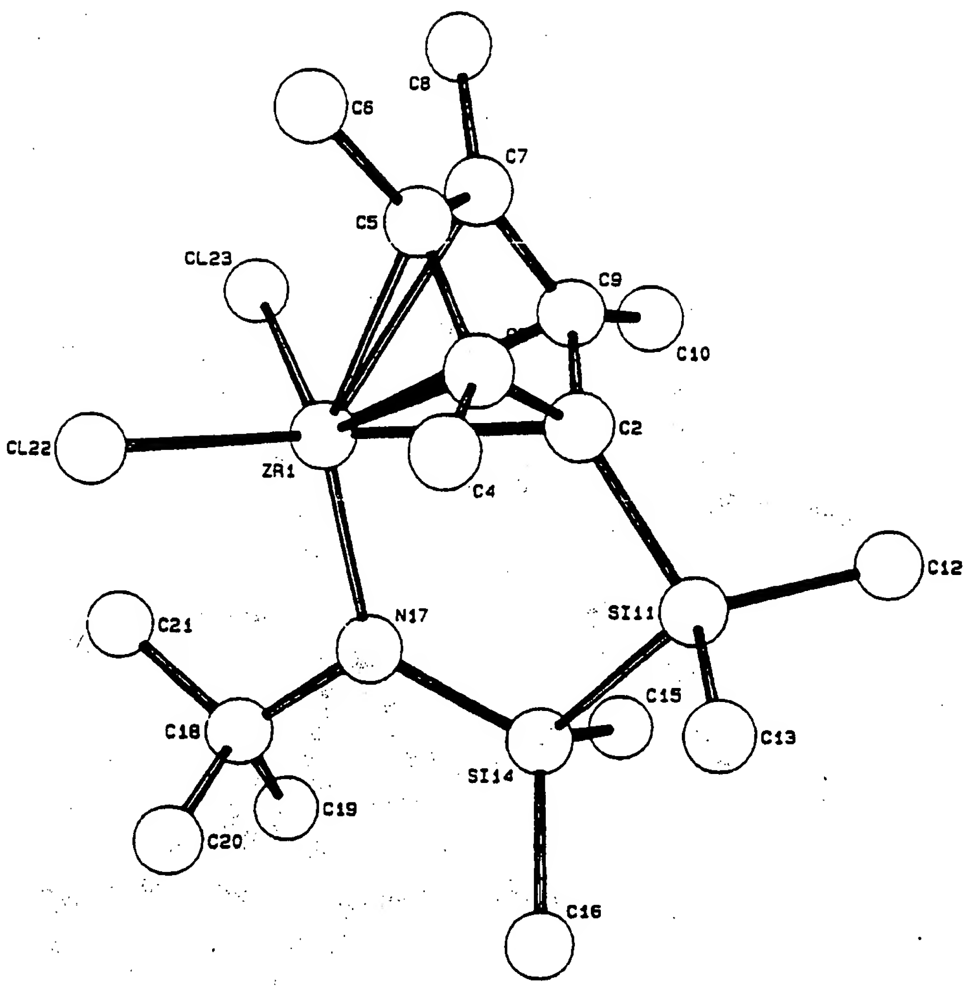

C8
C6
C7
C5
CL23
C9
C10
C2
CL22
ZR1
C4
C12
C21
N17
SI11
C15
C18
C13
SI14
C19
C20
C16

FIG.7

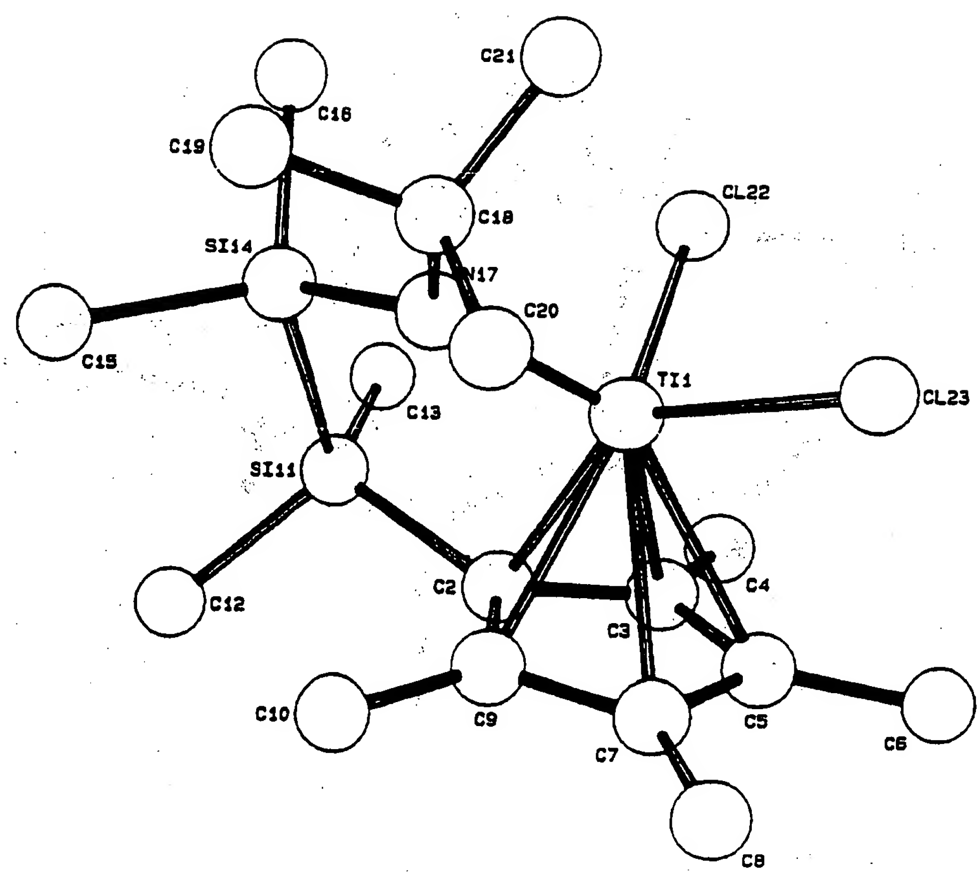

C21
C16
C19
C18
SI14
N17
C20
CL22
C15
TI1
CL23
C13
SI11
C12
C2
C4
C3
C10
C9
C7
C5
C6
C8

FIG.8

Ethylene / Styrene Pseudo-random Copolymer 1.4 Mole % Styrene, 15% Tail-to-Tail

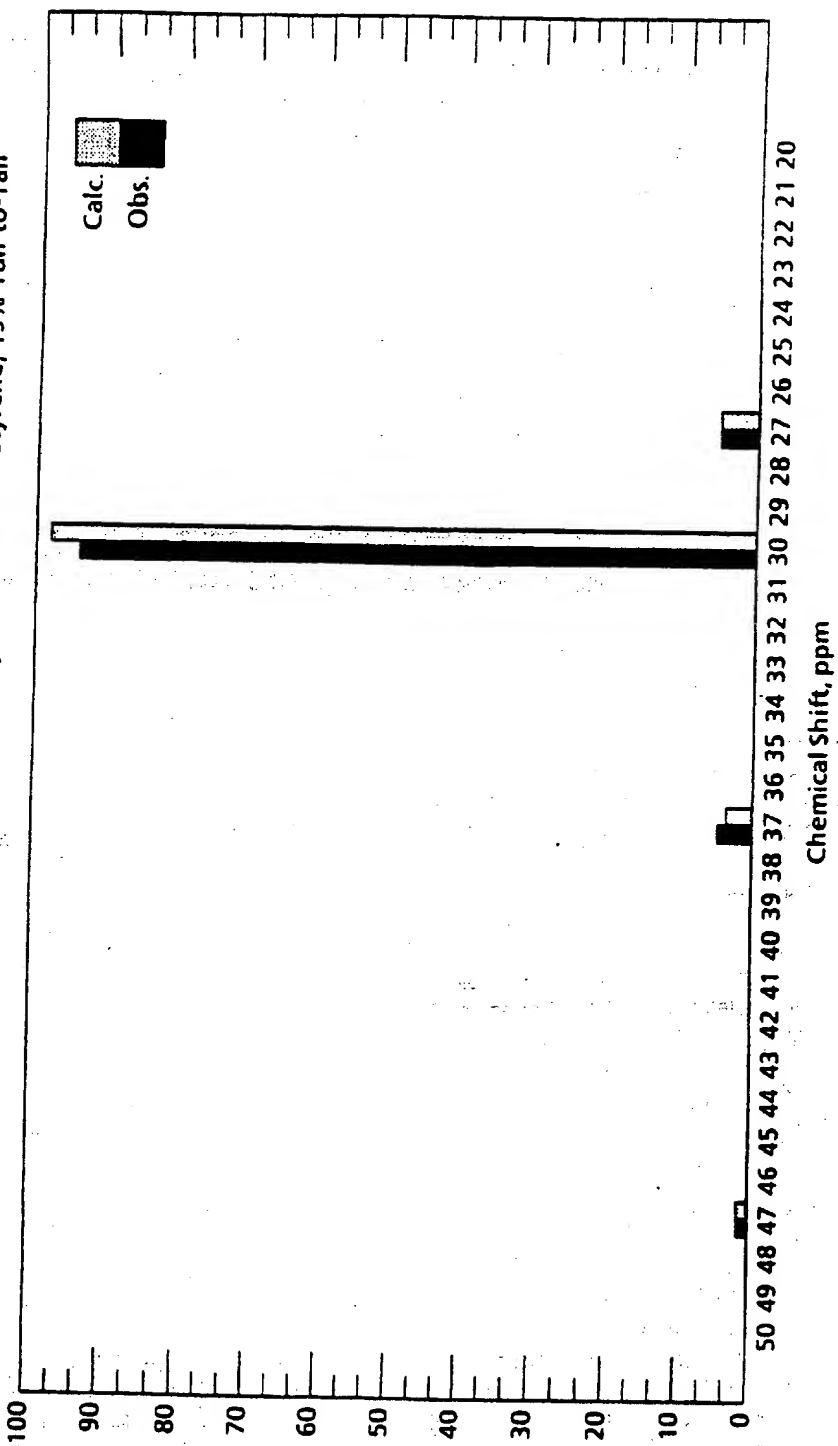


FIG.9

Ethylene / Styrene Pseudo-random Copolymer 4.8 Mole % Styrene, 15% Tail-to-Tail

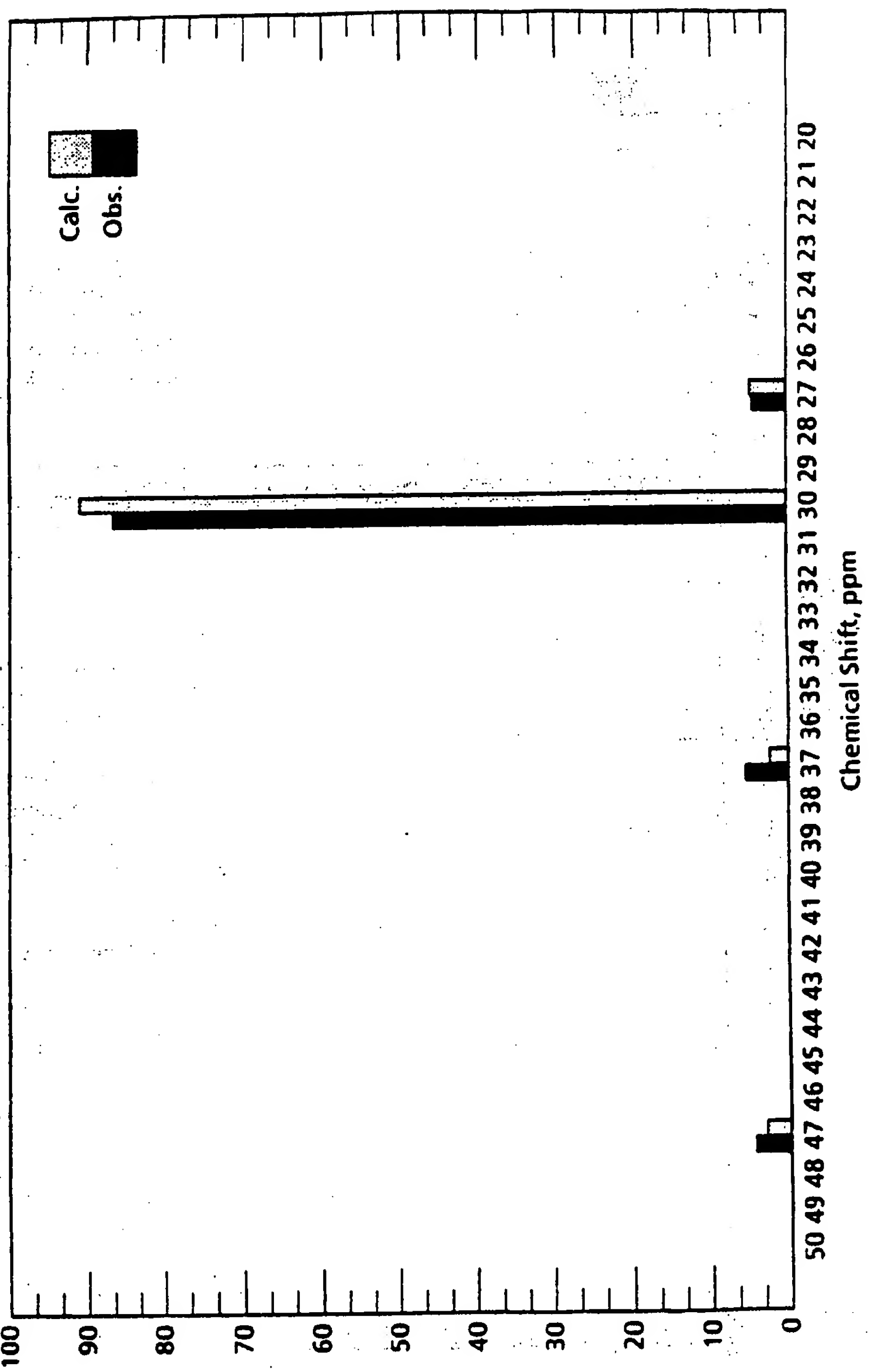


FIG.10

Ethylene / Styrene Pseudo-random Copolymer 9.0 Mole % Styrene, 15% Tail-to-Tail

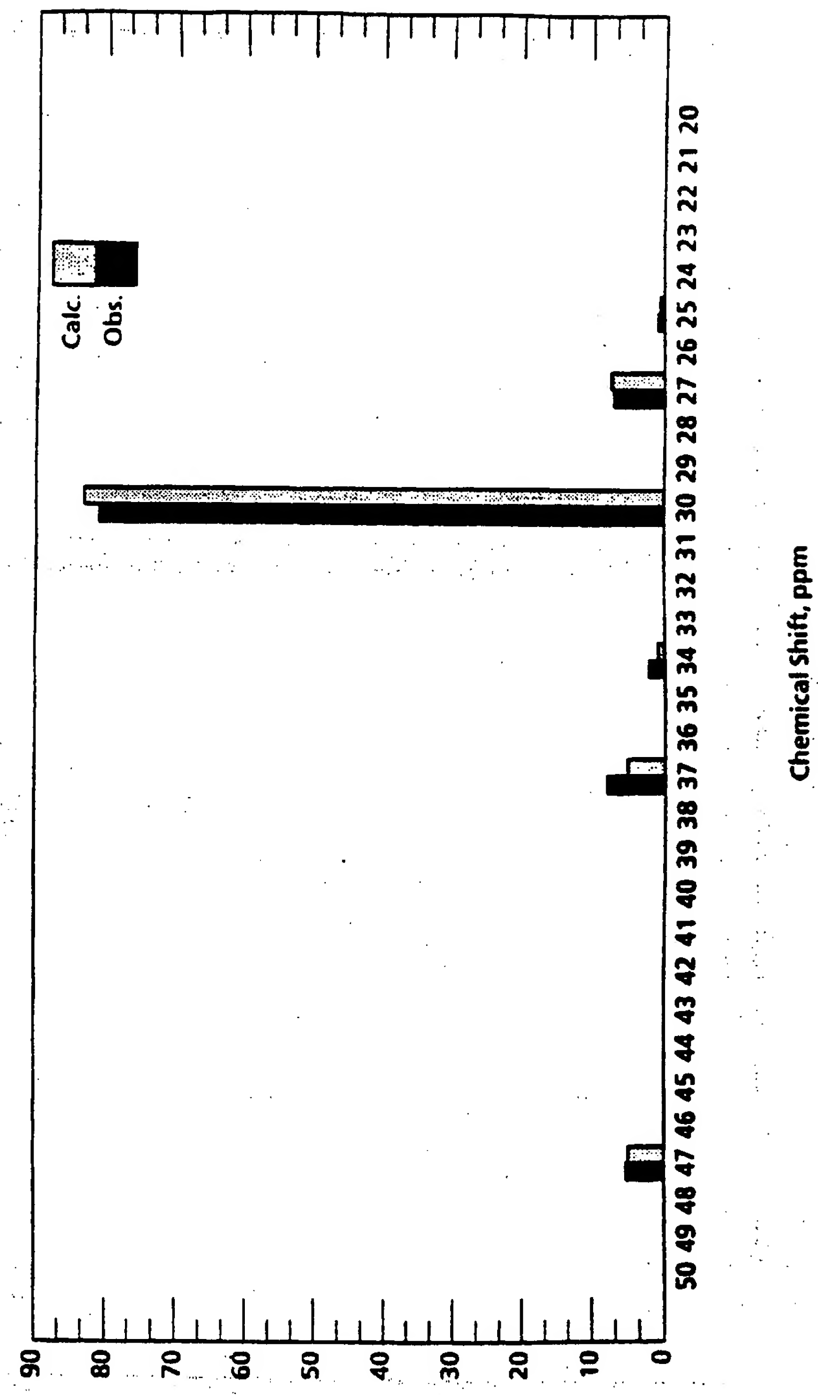


FIG. 11

Ethylene / Styrene Pseudo-random Copolymer 13.3% Mole Styrene, 15% Tail-to-Tail

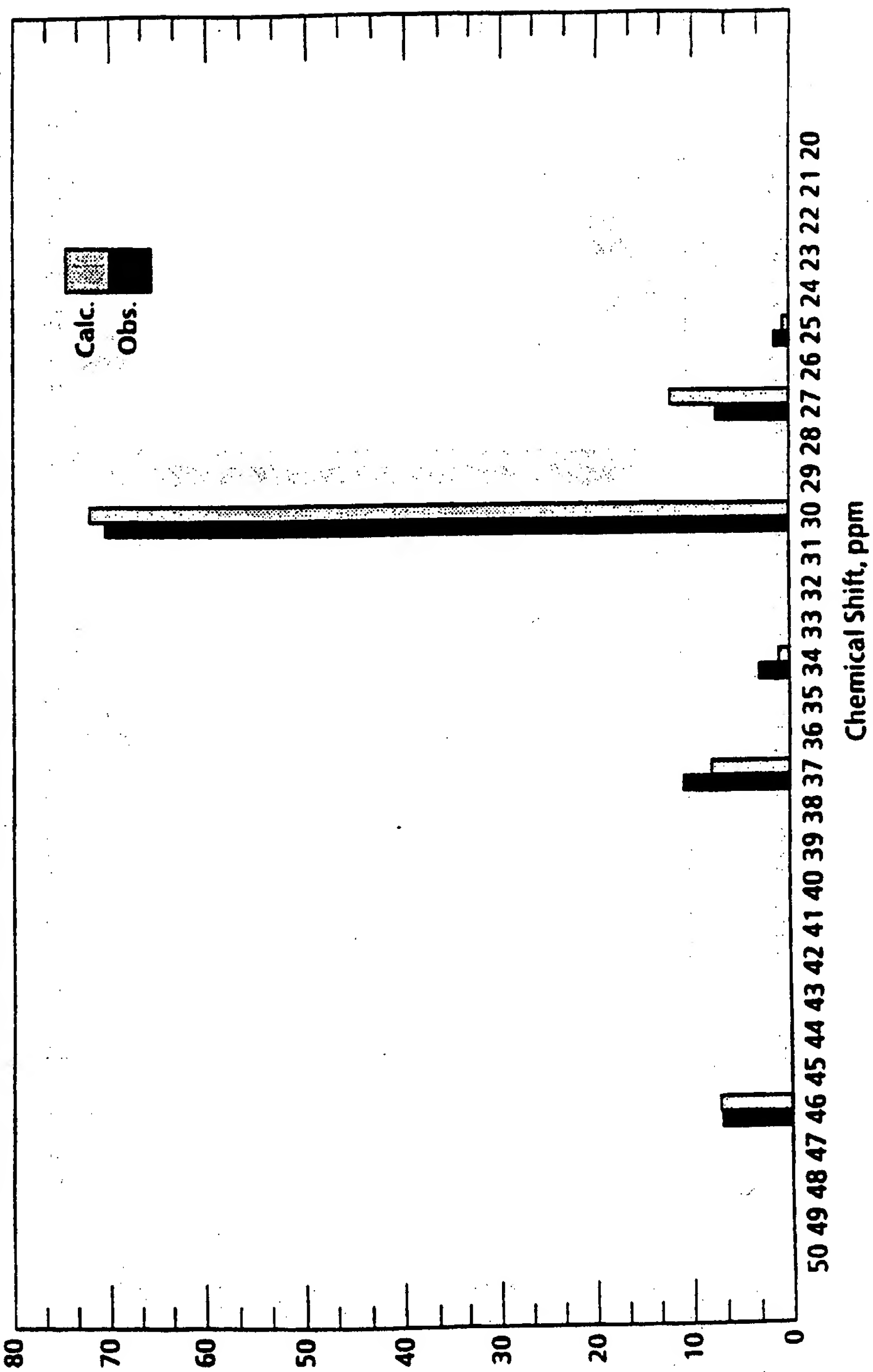


FIG.16

ELASTIC MODULUS V. MELT INDEX

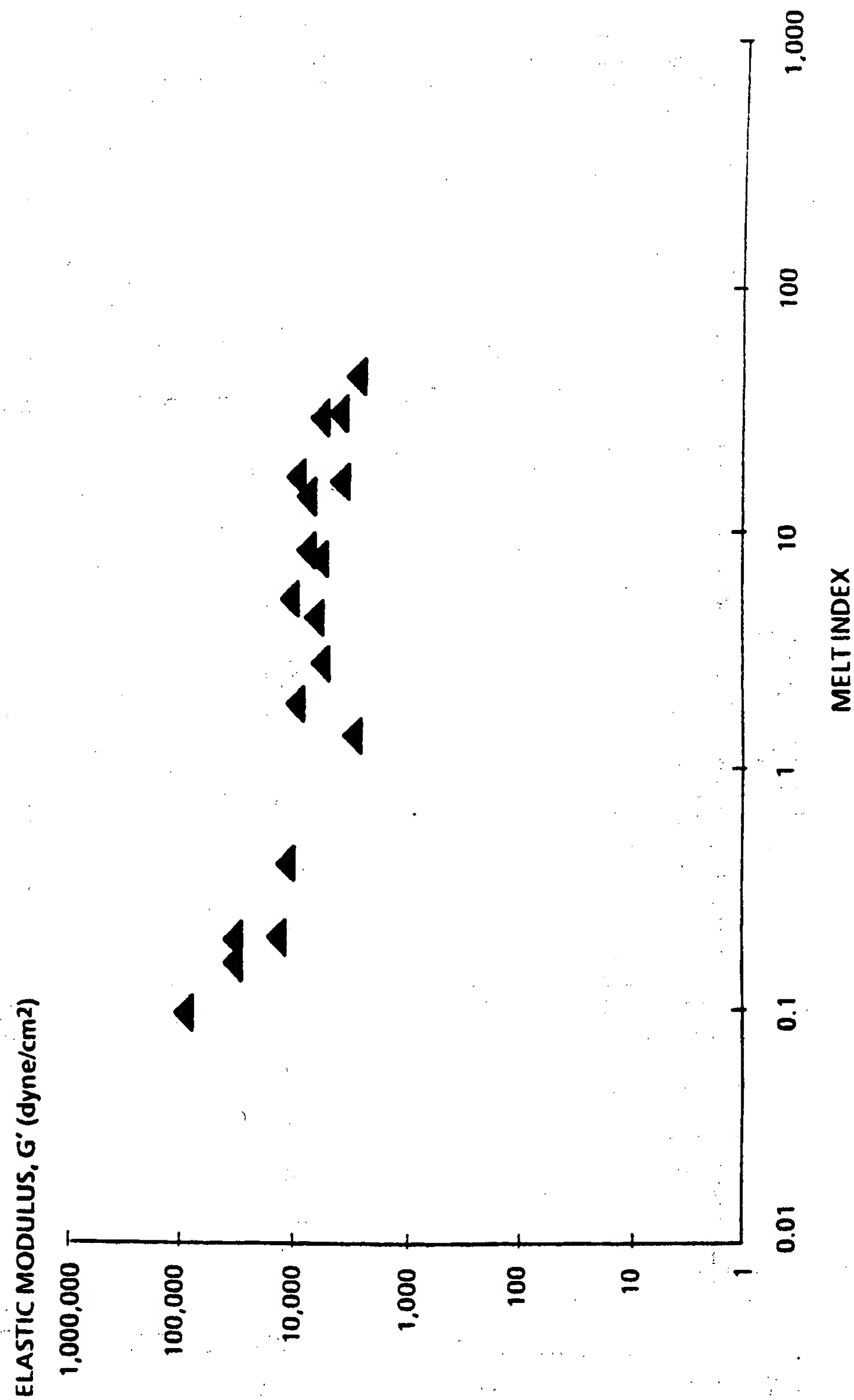
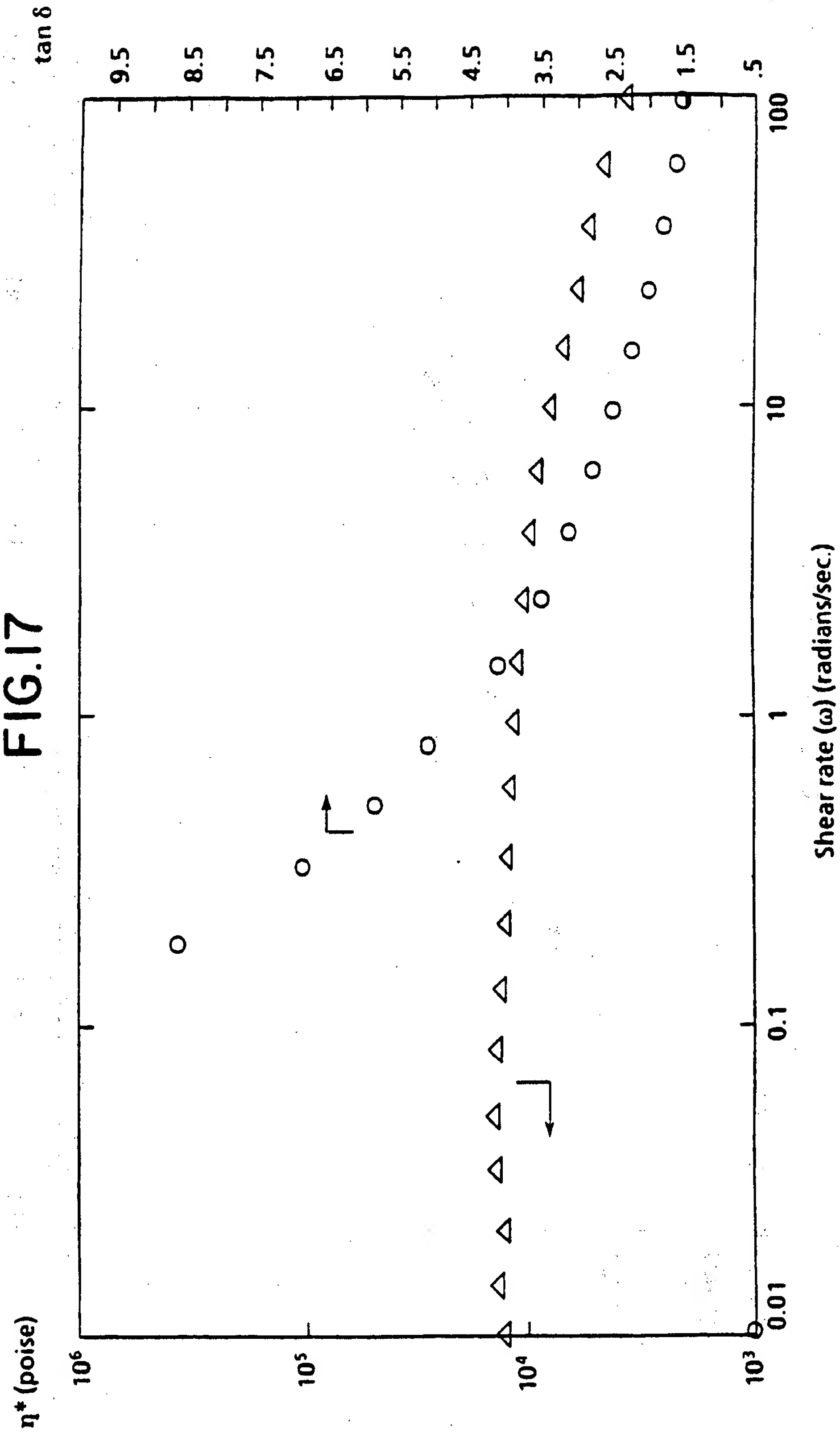


FIG.17



η* (poise)
10⁶
10⁵
10⁴
10³
tan δ
9.5
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
.5
0.01
0.1
1
10
100
Shear rate (ω) (radians/sec.)

FIG.14

Ethylene / Styrene Random Copolymer 37 Mole % Styrene, 15% Tail-to-Tail

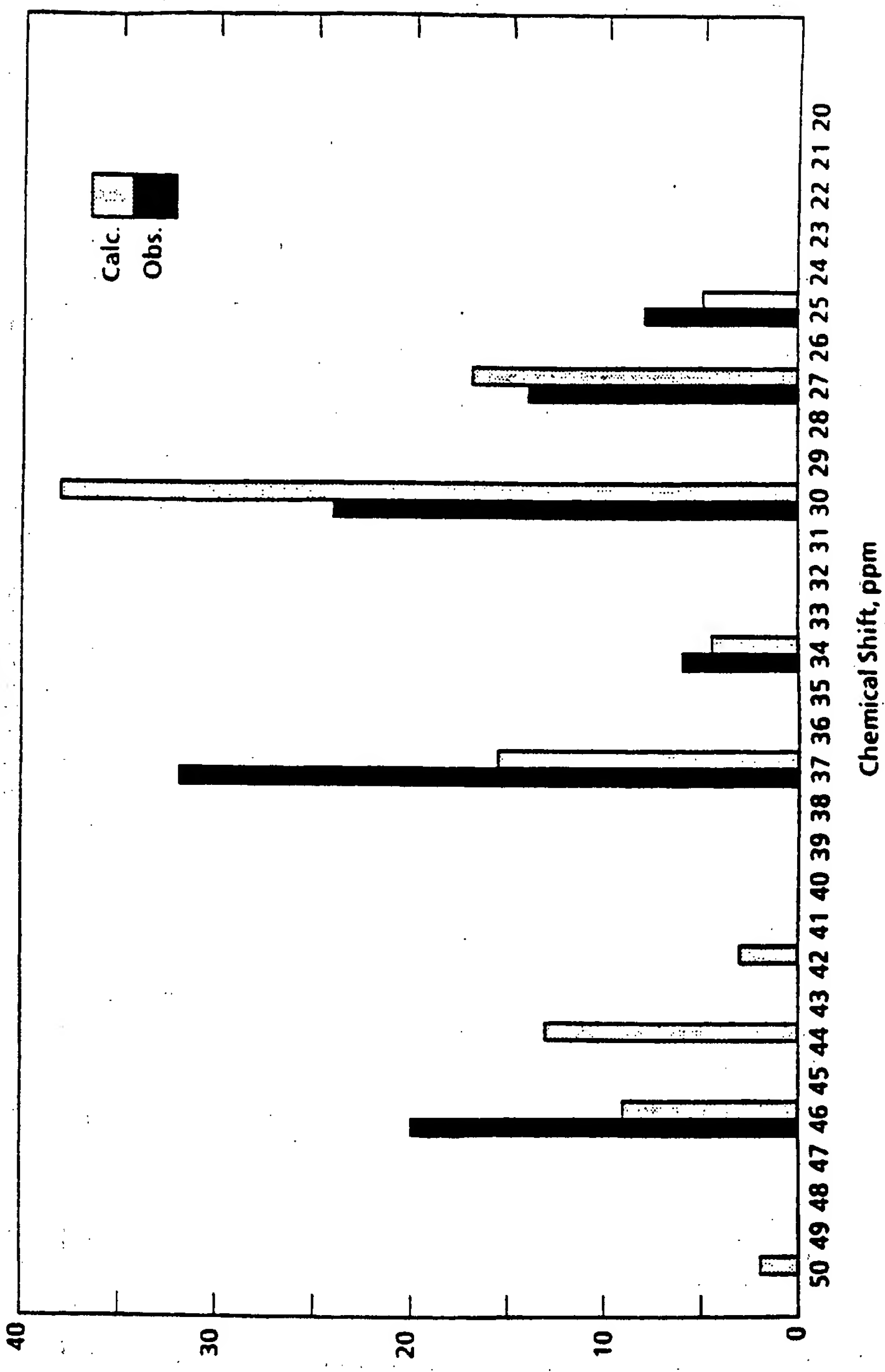


FIG.15

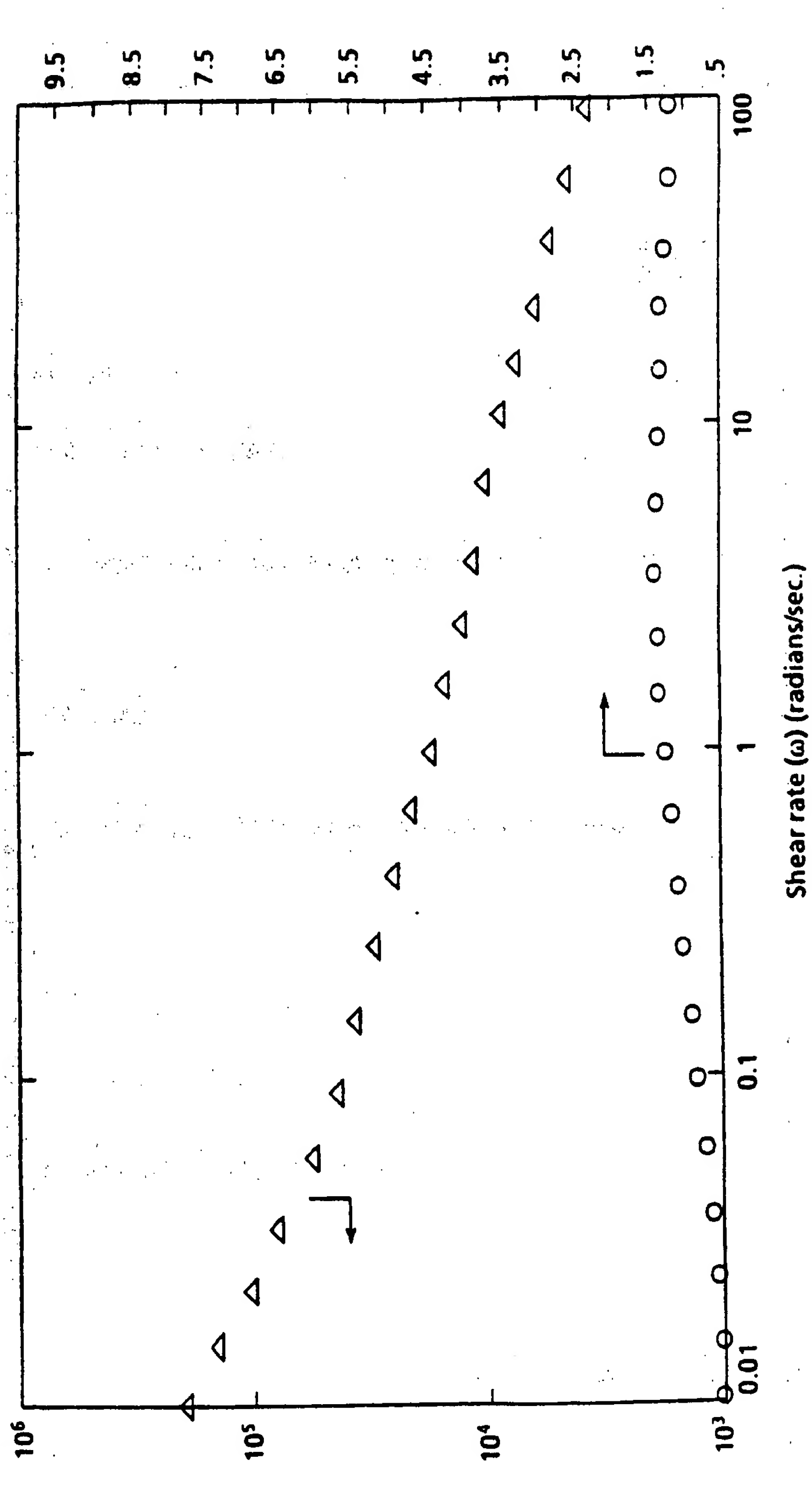

η* (poise)
tan δ
10⁶
10⁵
10⁴
10³
9.5
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
.5
0.01
0.1
1
10
100
Shear rate (ω) (radians/sec.)

FIG.12

Ethylene / Styrene Pseudo-random Copolymer 37 Mole % Styrene, 15% Tail-to-Tail

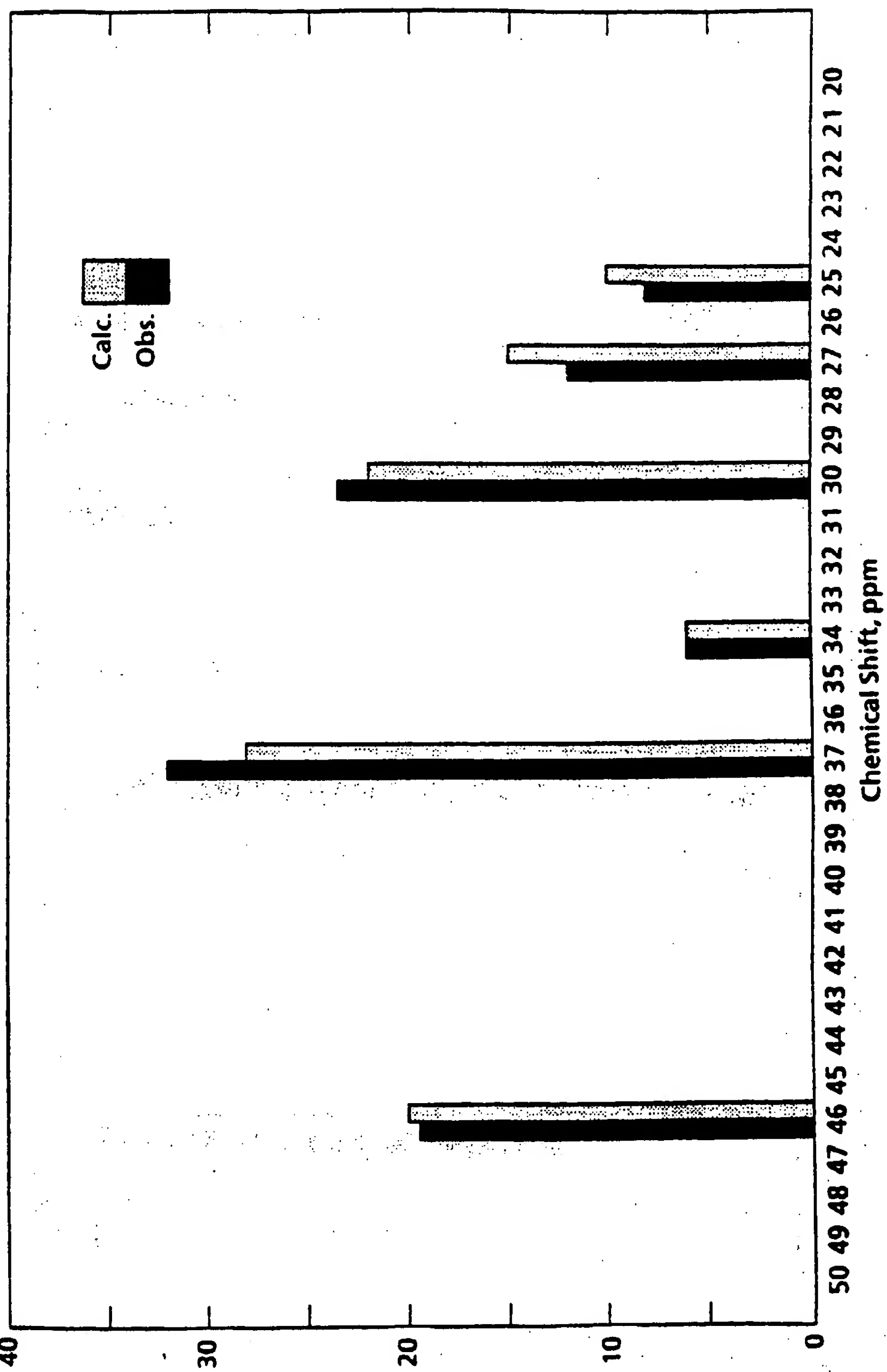
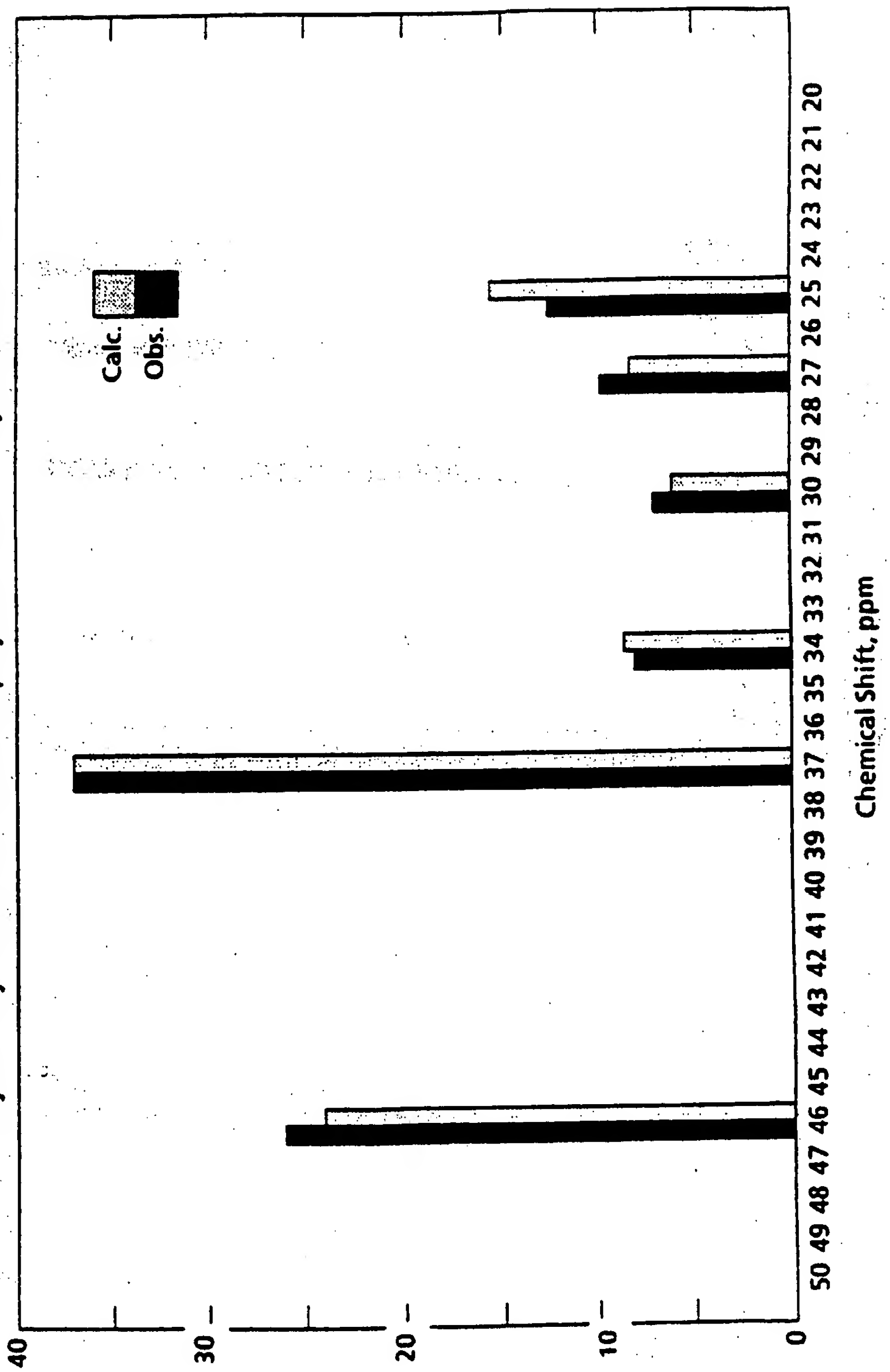


FIG.13

Ethylene / Styrene Pseudo-random Copolymer 47 Mole % Styrene, 15% Tail-to-Tail



NEW GENERATION HIGH PERFORMANCE LLDPE BLOWN FILM RESINS SUPERIOR PHYSICAL PROPERTIES AND PROCESSABILITY

BY

G. PANAGOPOULOS JR. AND L.G. HAZLITT

DOW PLASTICS
FREEPORT, TX 77541

I. Introduction

A new generation fractional melt index, broad molecular weight distribution LLDPE product with improved physical properties and processability has been developed. This paper will compare the physical properties, processing characteristics, and viscoelastic properties of this new LLDPE resin to conventional resins. This technology increases resin design flexibility, and allows for greater design and application uses; for example, a fractional melt index resin that fabricates similarly to a 1.0 melt index resin . The result is a new family of LLDPE blown film resins with higher tensile strength, greater bubble stability, lower melt fracture, and higher output than commercially available LLDPE resins. These materials should find utility in several applications, including T-shirt bags, heavy duty shipping sacks, high performance liners, shrink film, and coextrusions.

II. Materials

The materials evaluated in this paper are summarized in Table 1. Resins A-D are conventional ethylene-octene copolymers. Resin A,B, and C contain slip and antiblock additives while Resin B is barefoot. None of these materials contain any type of process aid. Resins HP1-HP3 are newly developed ethylene-octene copolymers with improved processability, resistance to melt fracture, and physical property performance. Also, these materials do not contain any process aid additives.

III. Experimental Procedure

The resins were fabricated into blown film at the Dow Polyolefins Technical Service and Development Laboratory in Freeport, Texas. A 2-1/2" extruder with a LLDPE barrier screw was utilized along with a 6" non-adjustable die. Samples were evaluated at 70-mil and 40-mil die gaps to measure the processability and property responses over a range of conditions. A 2.5:1 Blow-Up Ratio was used for all film fabrications. The film physical properties were measured under ASTM conditions. Rheological measurements were taken on a Rheometrics Dynamic Mechanical Spectrometer and a Gas Extrusion Rheometer.

IV. Processability Comparisons

A. Rheology

The viscosity versus shear rate data are summarized in Figure 1. In this plot, a high performance resin, HP1 is compared to two conventional ethylene-octene resins, A and B. In comparing the fractional melt index resins, HP1 and Resin B, one observes that the viscosity is greater for HP1 in the low shear regime of 0.01-0.1 sec^{-1}, but the viscosity of HP1 is lower than the conventional fractional melt index resin at higher shear regimes. The shear thinning effect observed with HP1 is not normally observed in commercially available LLDPE materials, and this characteristic is partially responsible for the improved processability of these materials compared to conventional fractional melt index, FMI, LLDPE's. In the higher shear regions, which are approaching the range of shear normally evidenced in the extruder, the viscosity of HP1 approaches that of Resin A which is a conventional 1.0 melt index LLDPE. Furthermore, high viscosities in the very low shear regime allow these high performance resins to exhibit exceptional bubble stability during blown film fabrication.

B. Gas Extrusion Rheology

The gas extrusion rheometer, GER, was utilized to characterize the resins at high shear rates. Past studies have indicated that a pressure jump in the GER curve can be correlated to the occurrence of melt fracture in film samples. In Figure 2, HP1 is compared to several conventional LLDPE resins. The pressure disturbance with HP1 is noticeably smaller than with the conventional resins. These data appear explain the ability of these high performance resins to process at high rates without melt fracture that is typical for conventional FMI LLDPE resins. The high performance resin extrudate did not evidence melt fracture while the other conventional LLDPE resins did have surface melt fracture.

C. Extrusion Comparisons

The extrusion characteristics of several high performance resins were compared to conventional ethylene octene materials on a 2-1/2" extruder. In these studies, a constant specific output was achieved for each resin by adjusting the screw speed. The process data at a 70-mil die gap are summarized in Table 2. High performance resin, HP1 is compared to a conventional 0.6 and 1.0 melt index LLDPE. HP1 extruded at lower amps and head pressures than the conventional fractional melt index resin, B. In fact, this 0.5 melt index high performance resin extrudes at only slightly higher amps than the 1.0 melt index resin, A. Finally, there was no melt fracture observed in the film samples from the fractional melt index, HP1, while resin B had

moderate amounts of melt fracture at the same output rates. The film physical property comparisons will be discussed below.

A similar extrusion study was conducted on the same equipment with a 40-mil die gap in order to further measure the processability and resistance to melt fracture of the high performance resins. In this study, HP1 is compared to a conventional FMI LLDPE, Resin D and a 1.0 melt index LLDPE, Resin C. Resin C is identical to resin A of the previous evaluation except resin C does not contain slip or antiblock. Once again, the high performance resin HP1 extruded at lower amps than the conventional FMI resin at the same specific output. At a lower melt index, the new high performance resins processed between a standard 1.0 and 0.6 melt index LLDPE. Furthermore, HP1 did not exhibit any detectable melt fracture at the 40-mil die gap while the conventional FMI resin, D, had severe melt fracture and even the 1.0 melt index resin, C, had slight melt fracture at this die gap.

In the third process comparison, Table 4, two additional high performance resins, HP2 and HP3, are compared to a 1.0 melt index conventional LLDPE, Resin C. HP2 is a 1.0 melt index resin while HP3 is a fractional melt index high performance resin. The high performance resin, HP2 processes at much lower amps and pressure than the conventional 1.0 melt index resin at the same output rates. In fact, even the 0.5 MI high performance resin, HP3 processes at lower amps than the standard 1.0 melt index resin. This data shows that the processability of the high performance resins can be altered dramatically to fit the application and targeted extrusion equipment.

V. Physical Property Comparisons

The film physical property comparisons between the high performance resin and the conventional LLDPE's are summarized in Tables 5-6. Table 5 summarizes the properties of 0.9 mil film fabricated with a 70-mil die gap. HP1 exhibits greater machine and cross direction tensile strength than a conventional FMI LLDPE, Resin B. The high performance resin, HP1 also has much greater Elmendorf Tear strength than Resin B in the machine and cross direction. In fact, the tear strength of HP1 is comparable to a 1.0 melt index resin of a much lower density (0.920 vs. 0.925). Finally, the dart impact results of HP1 and Resin B are similar and lower than Resin A which has a lower density.

Table 6 summarizes the physical properties of the film samples generated on the 40-mil die gap. Again, the high performance resin exhibited greater tensile strength and tear strength than the conventional FMI LLDPE. The dart impact is lowest for HPI as the other resins are lower in density. Finally, it is worth commenting that a good balance in properties can be achieved with the high performance

resins on a relatively narrow die gap without melt fracture. Conventional FMI resins exhibit severe melt fracture when extruded at these rates and a 40-mil die gap.without processing aids or other additives

VI. Conclusions

A new generation of high performance fractional melt index LLDPE has been developed. A 0.5 melt index new generation resin processes much easier at lower extruder amps and pressure than existing FMI LLDPE resins. Furthermore, FMI high performance resins can be designed to process easier than currently available 1.0 melt index LLDPE. These new materials can be fabricated without melt fracture on narrow die gaps without the addition of processing aids. The processability and melt fracture-free characteristics of these resins allow for a wide window of operation on a variety of extrusion equipment. The tensile and tear properties of the high performance FMI resins are superior to currently available FMI resins of comparable densities. In summary, the newly developed high performance resins offer dramatic improvements in processability, resistance to melt fracture, and physical properties compared to currently available FMI resins. The flexibility and performance characteristics should offer improvements in blown film applications such as: T-shirt bags, high performance liners, heavy duty shipping sacks, shrink, and coextrusions. The greater physical performance of these new resins will also allow for increased downgaugability, more than is possible with currently available LLDPE materials.

significantly less blocky

goals
1) downgauging
2) bubble stability
3) not splitty
4) 925 stiffer w/ 920 for U
5) strength w/o PPA

FIGURE 1

Low Shear Rheology Data

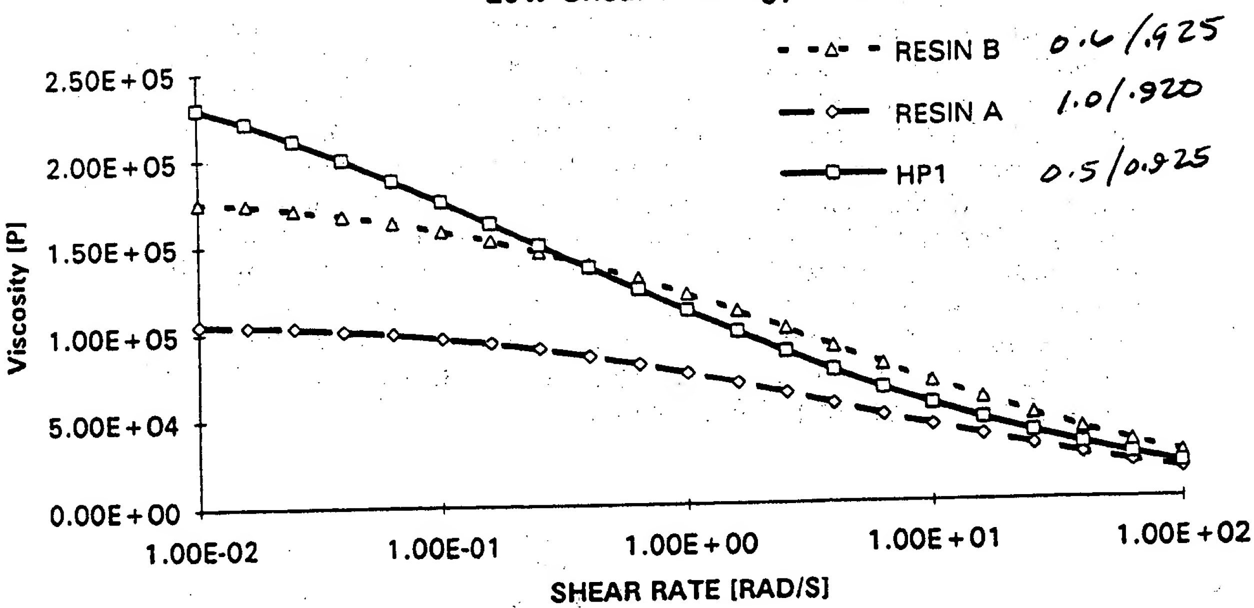
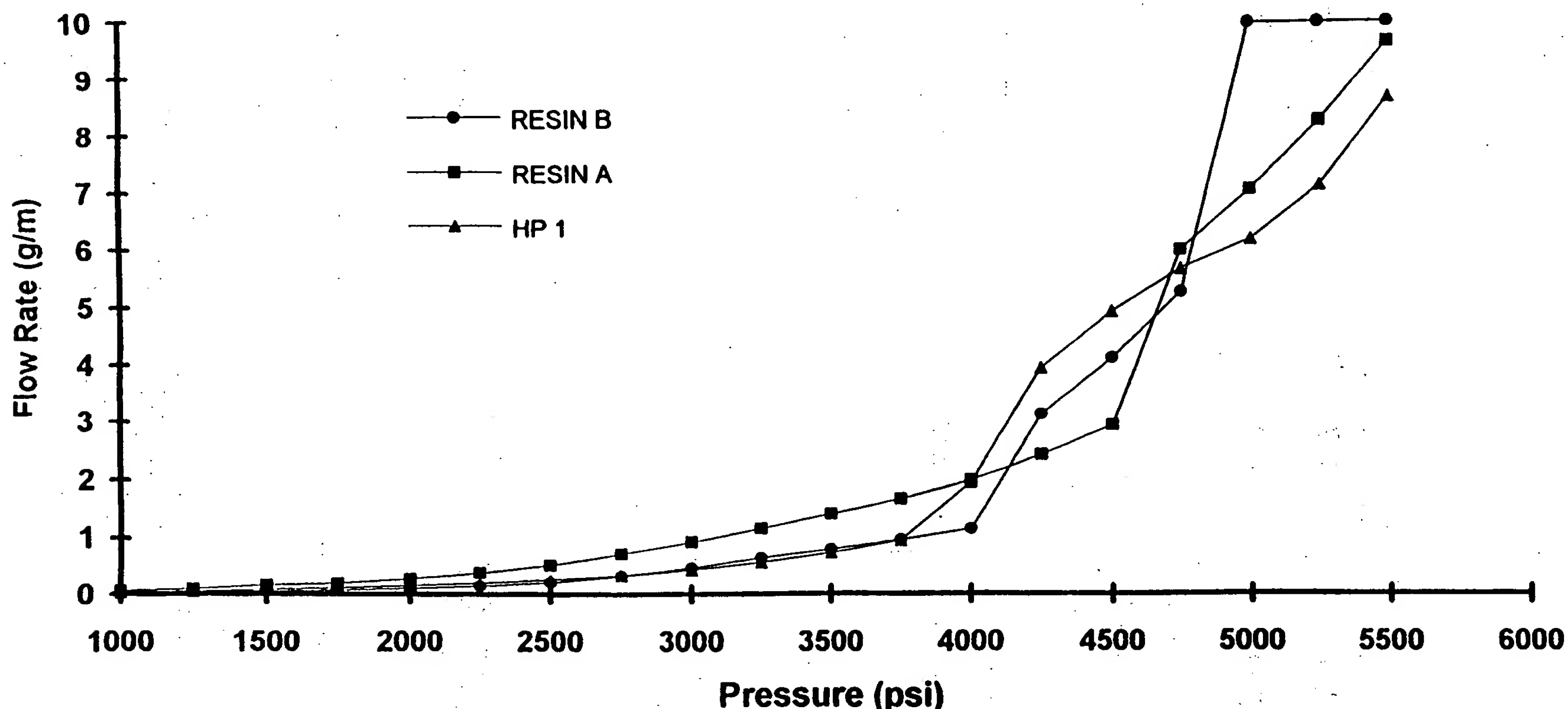


Figure 2

Gas Extrusion Rheometer Data



130-150g dat infast for 420/1HI (C8 old

TABLE I

Experimental Materials

RESIN	MI (g/10 min.)	I10/I2 (g/10 min)	Density (g/ml)	Additives
A	1	8	0.92	SLIP, ANTIBLOCK
B	0.6	7.5	0.925	SLIP, ANTIBLOCK
C	1	8	0.92	NONE
D	0.6	8	0.92	SLIP, ANTIBLOCK
HP1	0.5	10	0.925	SLIP, ANTIBLOCK
HP2	1.05	9	0.92	NONE
HP3	0.5	14	0.92	NONE

150 lb/hr
2½" ext
6" LLDPE die
dual lip air ring
220 melt

TABLE 2

PROCESS COMPARISONS- 70 MIL DIE GAP

	A	B	HP1
OUTPUT (LB/HR)	149.3	150.7	150.8
SCREW SPEED	51.6	66.9	65.9
AMPS	64	73	66
PRESSURE (PSI)	3470	4720	4050
MELT TEMP (C)	231	232	232
MELT FRACTURE	NONE	MODERATE	NONE

TABLE 3

PROCESS COMPARISONS- 40 MIL DIE GAP

	C	D	HP1
OUTPUT (LB/HR)	151.4	151	151.5
SCREW SPEED	67.3	65.8	75.2
AMPS	70	80	75
PRESSURE (PSI)	4810	5530	5930
MELT TEMP (C)	204	204	209
MELT FRACTURE	SLIGHT	SEVERE	NONE

TABLE 4

PROCESS COMPARISONS- 70 MIL DIE GAP

	C	HP2	HP3
OUTPUT (LB/HR)	150	151	152
SCREW SPEED	56	62.4	65.1
AMPS	72	61	67
PRESSURE (PSI)	3750	3380	4110
MELT TEMP (C)	213	213	214
MELT FRACTURE	NONE	NONE	NONE

TABLE 5

PHYSICAL PROPERTY COMPARISONS- .9 MILS

70 MIL DIE GAP

PHYSICAL PROPERTIES	A	B	HP1
ULT. TENSILE- MD (PSI)	7459	7471	9871
YIELD- MD (PSI)	1587	1830	2011
ELONGATION- MD %	566	479	438
ULT. TENSILE- CD (PSI)	6029	5312	6991
YIELD- CD (PSI)	1635	1869	2260
ELONGATION- CD (PSI)	648	613	660
ELMENDORF TEAR- MD (gms)	450	204	407
ELMENDORF TEAR- CD (gms)	720	540	869
DART IMPACT (gms)	368	151	148

HP2 HP3

TABLE 6

PHYSICAL PROPERTY COMPARISONS- 1.0 MIL FILM

40 MIL DIE GAP

PHYSICAL PROPERTIES	C	D	HP1	HP2 HP3
ULT. TENSILE- MD (PSI)	7321	8104	9940	8.3
YIELD- MD (PSI)	1676	1725	2003	
ELONGATION- MD %	616	497	407	
ULT. TENSILE- CD (PSI)	6553	4850	5795	
YIELD- CD (PSI)	1718	1663	2273	
ELONGATION- CD (PSI)	792	643	687	
ELMENDORF TEAR- MD (gms)	515	308	474	
ELMENDORF TEAR- CD (gms)	634	601	918	
DART IMPACT (gms)	343	408	168	
MELT FRACTURE	SLIGHT	SEVERE	NONE	